Prepared for the
GEORGE C MARSHALL
SPACE FLIGHT CENTER
Huntsville, Alabama

MAY, 1975

Contract No NAS8 31009
IBM No 75W-00072

IUS/TUG ORBITAL OPERATIONS and MISSION SUPPORT STUDY

FINAL REPORT

Vol III of V - Space Tug Operations

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Classification and Content Approval ______________________

Data Manager Approval ______________________

Program Office Approval ______________________

PHILCO
Philco Ford Corporation
Western Development Laboratories Division

IBM Federal Systems Division, Space Systems/Huntsville, Alabama

FOREWORD

This final report of the IUS/Tug Orbital Operations and Mission Study was prepared for the National Aeronautics and Space Administration, George C Marshall Space Flight Center by the IBM Corporation in accordance with Contract NAS8-31009

The study effort described herein was conducted under the direction of NASA Contract Officer's Representative (COR), Mr. Sidney P Saucier This report was prepared by the IBM Corporation, Federal Systems Division, Huntsville, Alabama, under the direction of Mr Roy E Day, IBM Study Manager. Technical support was provided to IBM by the Philco-Ford Corporation, Western Development Laboratories Division, Palo Alto, California, under the direction of Dr W E Waters, Philco-Ford Study Manager The study results were developed during the period from June, 1974, through February, 1975, with the final report being distributed in May, 1975

The results of this study have been documented in five separate volumes

Volume I	Executive Summary
Volume II	IUS Operations
Volume III	Tug Operations
Volume IV	Project Planning Data
Volume V	Cost Estimates

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ACRONYMS AND ABBREVIATIONS

ACN -	Ascension Island, STDN Ground Station
ACS -	Attitude Control System
ADS -	Advanced Data System
AFSCF -	Air Force Satellite Control Facility
AFSTC -	Air Force Satellite Test Center
AGE -	Automated Ground Equipment
AGO -	Santiago, Chile - STDN Ground Station
AOA -	Abort-Once-Around
AOS -	Acquisition of Signal
ATO -	Abort-To-Orbit
AZ-EL -	Azimuth - Elevation
BDA -	Bermuda (U.K) - STDN Ground Station
BITE -	Built In Test Equipment
B/U -	Backup
C&D -	Control and Display
C&W -	Caution and Warning
CCTV -	Closed Circuit Television
CIU -	Computer Interface Unit
CMDS -	Command
C/O -	Checkout
CPU -	Central Processor Unit
CYI -	Canary Island - STDN Ground Station
D/A -	Deployment Adapter
DFCS -	Digital Flight Control System
DIU -	Digital Interface Unit
DMS -	Data Management System
DoD -	Department of Defense
DSN -	Deep Space Network
EIUS -	Expendable Interim Upper Stage
EVA -	Extravehicular Activity
FPS -	Feet Per Second
GDS -	Goldstone, Calif - STDN Ground Station
GMT -	Greenwich Mean Time
GN&C -	Guidance, Navigation and Control
GND -	Ground
GPCF -	General Purpose Control Facility
GSE -	Ground Support Equipment
GSFC -	Goddard Space Flight Center, Greenbelt, MD
GWM -	Guam Island - STDN Ground Station
HAW -	Hawaii - STDN Ground Station
HSK -	Honeysuckle Creek (Canberra), Australia - STDN Ground Station
IGPS -	Inertial Guidance Power System
IGS -	Inertial Guidance System

IMU -	Inertial Measuring Unit
IOP -	Input/Output Processor
IUS -	Interim Upper Stage
IUS/OC -	Interim Upper Stage Operations Center
JPL -	Jet Propulsion Lab, Pasadena, California
JSC -	Johnson Spacecraft Center, Houston, Texas
KADS -	Kilo-Add Instruction Executions Per Second
KBPS -	Kilobits Per Second
KM -	Kilometers
KOPS -	Kilo-Operations Per Second
KS -	Kick Stage
KSA -	Ku-Band Single-Access
KSC -	Kennedy Space Center, Cape Canaveral, Florida
LLTV -	Low Light Level TV
LOS -	Loss of Signal/Line of Sight
LPS -	Launch Processing System
MA -	Multiple Access
MAD -	Madrid, Spain - STDN Ground Station
M&O -	Maintenance and Operations
MBPS -	Megabits Per Second
MCC -	Mission Control Center
MDM -	Multiplexer/Demultiplexer (Orbiter)
MGC -	Missile Guidance Computer (IUS)
MHz -	Megahertz
MIL -	Merritt Island, Florida - STDN Ground Station
MPS -	Main Propulsion System
MR -	Mixture Ratio
MSFC -	Marshall Space Flight Center, Huntsville, Alabama
MSS -	Mission Specialist Station (Orbiter)
NASA -	National Aeronautics and Space Administration
NASCOM -	NASA Communications Network
NOCC -	Networks Operations Control Center
ODS -	Orbit Determination System
ORR -	Orroral, Australia - STDN Ground Station
OS -	Operating System (Software)
PCM -	Pulse Code Modulation
PDI -	Payload Data Interleaver (Orbiter)
PMOCC -	Pioneer Mission Operations Control Center
PMS -	Performance Monitoring System
PN -	Pseudonoise
POCC -	Project Operations Control Center
PSP -	Payload Signal Processor (Orbiter)
PSS -	Payload Specialist Station (Orbiter)
PU -	Propellant Utilization

ACRONYMS AND ABBREVIATIONS (Continued)

QUI -	Quito, Equador - STDN Ground Station
RCS -	Reaction Control System (Orbiter)
RF -	Radio Frequency
RFI -	Radio Frequency Interference
RIUS -	Reusable Interim Upper Stage
RMIS -	Remote Multiplexer Instrumentation System (IUS)
RMS -	Remote Manipulator System (Orbiter)
RMU -	Remote Multiplexer Unit (IUS)
ROS -	Rosman, N C - STDN Ground Station
R&RR -	Range and Range Rate
RTCC -	Real Time Computer Complex
RTLS -	Return-To-Launch-Site
RTS -	Remote Tracking Station
SA -	Single Access
SC -	Spacecraft
SCF -	Satellite Control Facility
SCOC -	Spacecraft Operations Center
SGLS -	Space Ground Link System
SIRD -	Support Instrumentation Requirements Document
SOC -	Shuttle Operations Center
SPO -	Space Project Office
SSA -	S-Band Single Access
STDN -	Spaceflight Tracking and Data Network
TAN -	Tananarive, Malagasy Republic - STDN Ground Station
TBD -	To Be Determined
TDRS -	Tracking and Data Relay Satellite
TDRSS -	Tracking and Data Relay Satellite System
THI -	Tank Head Idle
TM -	Telemetry
TOC -	Tug Operations Center
TPI -	Terminal Phase Initiation
TPT -	Terminal Phase Transfer
TTY -	Teletype
ULA -	Fairbanks, Alaska - STDN Ground Station
ZOE -	Zones of Exclusion
ΔV -	Delta Velocity

VOLUME III

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

INTRODUCTION 1

This volume contains the background data and study results for the Space Tug portion of the IUS/Tug Orbital Operations and Mission Support Study For the purpose of this final report the contract name has been shortened to "Orbital Operations Study" This volume also contains the Transition Phase Analysis results, which is the transition from IUS to Tug operations The analysis results supported the Tug costing which is detailed in Volume V All Space Tug data, except costing details, are included in this volume

1 1 BACKGROUND

The Space Transportation System will include a propulsive stage that is carried to low earth orbit by the Space Shuttle (Orbiter) The Space Tug will be a newly developed vehicle by the National Aeronautics and Space Administration for use by both NASA and DoD projected to be operational in 1984 The expendable IUS may also be used for selected missions after 1984

1 2 PURPOSE AND SCOPE

The Basic purpose of this phase of the Orbital Operations Study was to develop Tug operational concepts, a Tug Baseline Operations Plan, and to provide cost estimates for Space Tug operations. An overall study approach for the Tug Operations Phase is shown in Figure 1 2 0-1. The basic Tug study approach was to compile and evaluate baseline concepts, definitions and system, and to use that data as a basis for the Tug operations phase definition, analysis and costing analysis The operational analysis led to the Tug operational concepts and the Tug Baseline Operations Plan In addition, special emphasis trades and the transition phase analysis were performed

Both autonomy level II and III configurations were analyzed during the study The Space Tug with the Two autonomy levels were developed early in the study to provide a basis for preliminary costing and operations evaluation During the latter phases of the study, a basically autonomous Level II Tug was utilized for major emphasis during the final three months of contracted effort Transition phase analysis was based on the operational activities of an expendable IUS (Level B) to the Space Tug (Level II)

The major emphasis items for the Orbital Operations study was on-orbit operations and interfaces with the Orbiter, the Tracking and Data Relay Satellites, ground station support capability analysis, and flight control center sizing to support the Tug mission requirements.

1 3 DOCUMENT OUTLINE

The following paragraphs give a brief overview of the type of information continued in each of the sections inluded in this volume of the final report

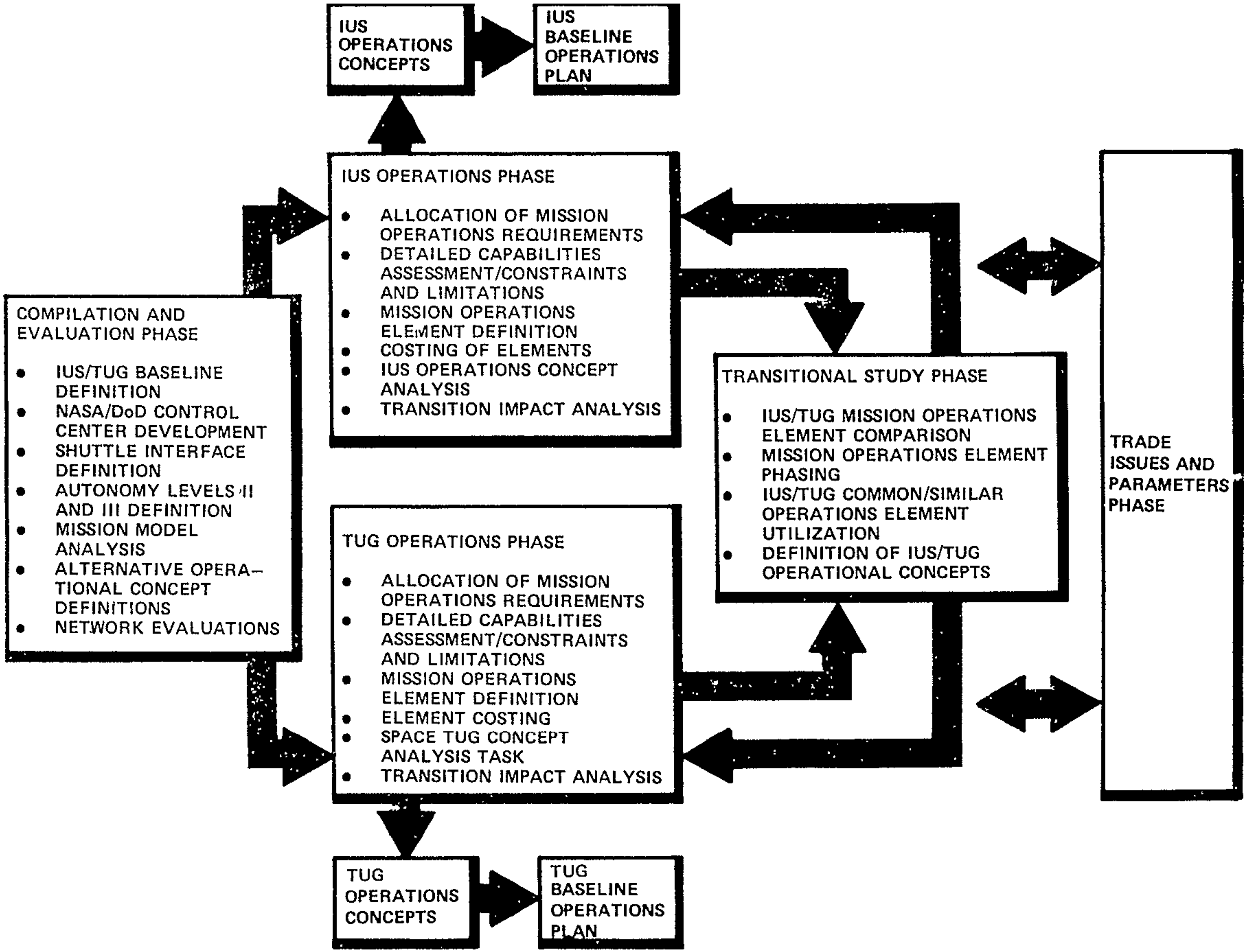

Figure 1 2 0-1 IUS/Tug Overall Study Approach

- Section 2 0 - Gives a summary of the Tug operational and interface requirements with emphasis on the on-orbit checkout requirements, Tug external interface operational requirements, safety requirements, and Tug system operational interface requirements

- Section 3 0 - Gives a brief summary of the reference missions baselined for the Tug and details for the mission functional flows and timelines derived for the Tug mission.

- Section 4 0 - Gives an overview of the Tug subsystems, with emphasis on component description and characteristics which would be used for flight operations analysis

- Section 5 0 - Provides the operational interfaces definitions for the Tug interface with the Orbiter, the Spacecraft, Ground Control Center, with emphasis on the Tug Orbiter operational interfaces, and Caution & Warning parameter definitions.

- Section 6 0 - Gives a detailed discussion of the Tug on-orbit operations (pre and post deploy) prior to the Tug first burn Items emphasized include checkout philosophy, activation and monitoring functions, allocation of functions, and Orbiter software impacts to support the Tug

- Section 7 0 - Discussed the operations related to Spacecraft deployment and retrieval by the Tug. Major emphasis in this section defines Tug support during rendezvous and docking operations

- Section 8 0 - Gives an overview of the STDN and TDRSS characteristics/data flow, an analysis of the communication interface support available for Tug missions, discussion of the Tug, Spacecraft, and Orbiter operations center interfaces, and an analysis of potential problem areas in the design of a new operations center

- Section 9 0 - Presents the Tug Baseline Operations Plan It contains the mission plan overview, the functional organization for flight control and flight support personnel, the mission control group functions and definitions, the ground and flight support hardware/software descriptions and summaries the Tug cost estimates generated during the study.

- Section 10 0 - Presents the IUS/Tug operations transition definitions and plan with summary cost data

- Section 11 0 - Gives an overview of potential problem areas or impact areas defined during the Orbital Operations study

- Section 12 0 - Gives the references used to aid in the development of Volume III

- Appendix A - Gives the baseline requirements deleted during IUS/TUG Orbital Operations and Mission Support Study.

- Appendix B - Presents the Space Shuttle C&W definition as related to Space Tug.

FLIGHT OPERATIONAL BASELINE REQUIREMENTS ANALYSIS 2

2 0 OPERATIONAL REQUIREMENTS ANALYSIS

The purpose of the operational requirements analysis is to develop an understanding of Tug Orbital Operations functions and to provide a requirement package for further usage The summary requirements could then be used as authority as well as check points to assure NASA requirements had been accomplished The baseline requirements had to be assembled and interpreted to arrive at a clear understanding of the Tug peculiar problems relative to Orbital Operations The five main areas of the requirements analyzed were

- Mission Operations
- Space Tug Interfaces
- Space Tug Orbital Checkout
- Space Tug Safety Critical Operations
- Space Tug Systems

2 1 MISSION OPERATIONS REQUIREMENTS ANALYSIS SUMMARY

The objective of analyzing and summarizing mission operations requirements from baseline documentation was to

- Perform trades and sizings with authenticity supported by the baseline
- Provide traceability of study conclusions to baseline data
- Perform studies at the greatest level of detail supportable by baseline documentation
- Take full advantage of prior study results
- Coordinate this study with concurrent studies through adherence to the common baseline

Since the identification, trading, and sizing of mission operation and mission support requirements is sensitive to the time of occurrence and duration of the requirement, the Mission Operations Requirements were summarized into timelines

2 1 1 Generation of Mission Operations Timelines

The approach taken to the generation of these Mission Operations Requirements Timelines is shown in Figure 2 1 1-1 Modular building blocks which can be

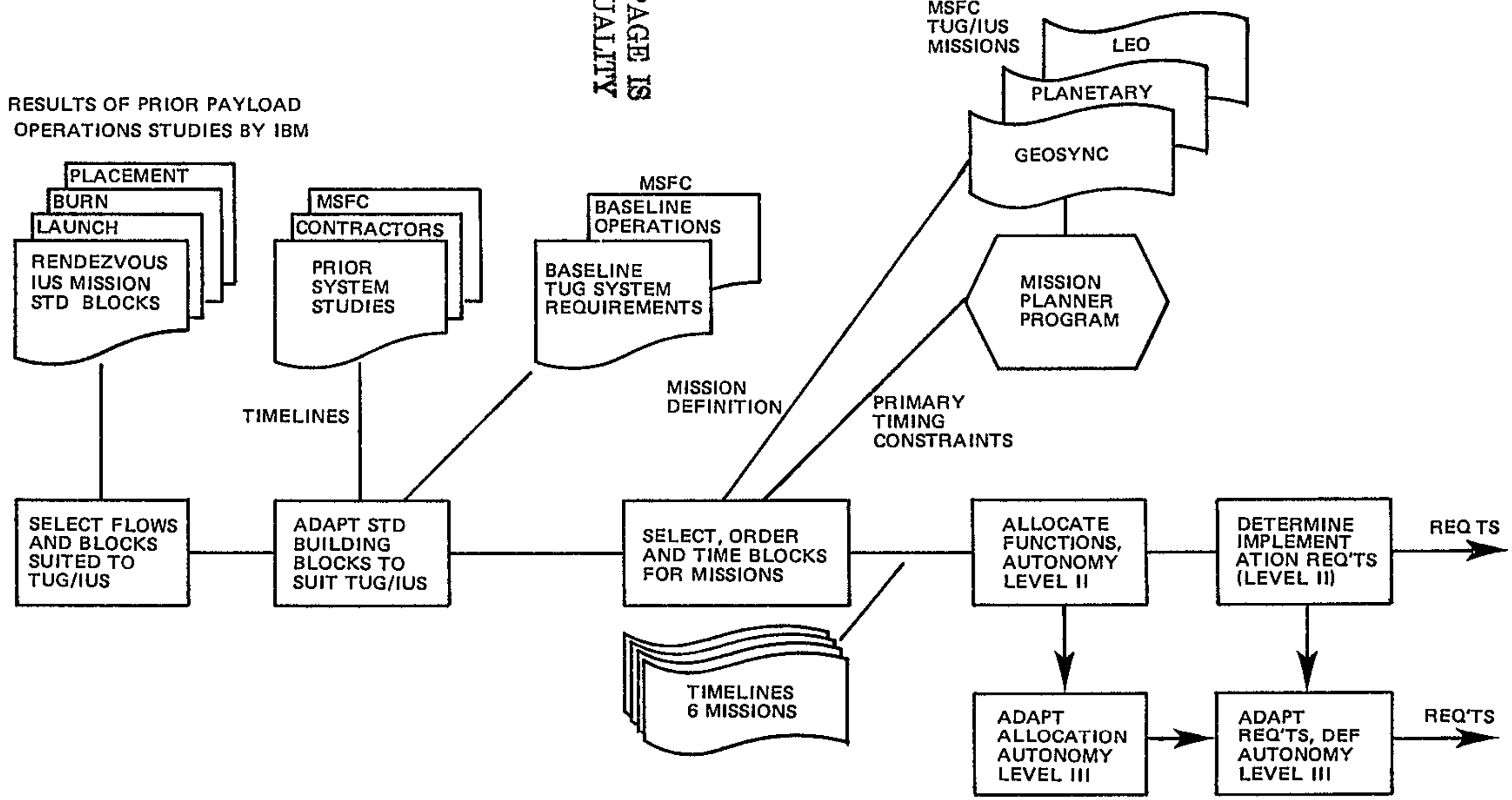

Figure 2 1.1-1 IUS,Tug Operational Timeline Generation Flow

sequentially assembled to make up specific Tug missions from pre-launch to landing were selected from IUS/Tug Operational Studies performed previously by IBM for NASA and DoD Next, the Baseline Space Tug Flight Operations and System Requirements and Guidelines documents were carefully analyzed and the point-of-departure timeline building blocks were modified, constrained, and supplemented to incorporate all provisions of this baseline documentation

Some of these requirements derived from baseline documentation were in the form of explicit events to be included in the timelines e g , "Tug Mission Sequence for SC Delivery and Retrieval", page 29, Figure 11 of Volume 3, Baseline Space Tug Flight Operations Other requirements for mission operations were implied from baseline documentation e g , main engine "enables" were added to timeline building blocks to implement Volume 1 (Baseline Space Tug System Requirements and Guidelines), page 74, Paragraph 4 requirements for interlocks to prevent inadvertent operations of the Spacecraft while in the Orbiter payload bay or during the deployment phase of operation Similarly, Volumes 2 and 4 (Baseline Space Tug Configuration Definition and Baseline Space Tug Ground Operations Verification, Analysis and Processing, respectively) were analyzed for implied mission operations requirements and appropriate adaptions were made in the point-of-departure module definitions. Further resolution was added to the resulting Standard Mission Timeline Modules by incorporation of prior Tug Systems Study results Next, specific event (e g , main engine burn) times provided by the Mission Planner Program were placed within the appropriate Standard Modules and the resulting "Reference Times" within the modules provided for their sequencing with other modules to make up total mission timelines This process yielded standard timeline modules for all mission phases such as launch, deployment, and retrieval which were keyed to times within specific missions It also identified detailed activities required to precede and follow key events such as the initialization of GN&C before an engine burn and ground tracking following the burn Sequences and timing of these supporting activities were then determined from baseline and Tug Systems Study documentation to place them in time around the reference times

2.1 2 Special Cases in Mission Operations Requirements Derivation

Determination of On-orbit Service, and Abort mission operations requirements and timelines necessitated the analysis of additional documentation McDonnell Douglass documents such as "IUS/Tug Payload Requirements Compatibility Study", (1974) were analyzed in much the same manner as described previously for the baseline documentation The limited amount of On-orbit Servicing Operations definition in the baseline documentation necessitated the gathering and analysis of other documentation covering several of the servicing approaches One of these is described in the Tug Operations and Payload Support Study Volume 3, dated March 1973 Another approach is defined in the Payload Utilization of Tug report, Volume 2, June 1974 which defined a seven element service timeline module using a module-exchange satellite servicer This was adapted to be non-specific to the servicer mechanisms and other servicing approaches such as the remote-manipulator servicer An IBM Standard Service Module was defined in a flow and timeline to fit within the IBM Standard Docking Module and the IBM Standard Payload Placement Module The reference time for this module was defined as the completion of latch between Tug and SC (to eliminate overlap in the micro-rendezvous) Detailed servicing

operational requirements were implied from a careful review of the several servicing approaches and generalization of the IBM Standard Service Module definition to allow overall compatibility with all approaches being considered

Baseline Space Tug System Requirements & Guidelines specifies in Paragraph 3 2 1 1 1 3 1, "The Tug shall be compatible with all Shuttle abort modes and procedures specified in JSC 07700, Volume X and XIV, January 1974" These documents specified abort requirements in terms of

- Return to Launch Site
- Abort Once Around
- Abort to Orbit
- Abort from Orbit

Operations requirements timelines and flows referencing agreement with the above specifications were published in the "Space Tug/Shuttle Interface Compatibility Study, September 1974" Additional information on abort mission operations requirements was derived in the study "Gross Abort Effects on STS Elements" and was published in Appendix B of "DoD/NASA System Impact Analysis (Study 2 1) Final Report, Volume II, September 1973 This information was used in generating the IBM Standard Abort Module flow and timeline which interfaces with the IBM Standard Launch Module and the IBM Standard Retrieval Module It conforms to the abort requirements specifications of JSC noted above and observes mission operational requirements specified in the baseline documents such as dump time contraints and thermal conditions for abort situations named in Baseline Space Tug System Requirements and Guidelines (Paragraph 3 2 6 1 4)

2 1 3 Assessment of Mission Operation Support Requirements

Flows and timelines which resulted from the analysis of mission operations requirements were, themselves, analyzed to determine their implementation requirements Several assessments were made under differing guidelines (such as those which distinguish autonomy levels) More than 100 potential implementation requirements were considered for each of the activities in the Standard Timeline Modules These were assessed for each of the implementing agencies Space Tug, Network, Orbiter, TOC, Payload, SOC, and POC The resulting implementation requirement definitions provide the means for quantitative evaluation of trade studies and for the sizing and costing of candidate implementation approaches

2 2 SPACE TUG INTERFACE OPERATIONAL REQUIREMENTS ASSESSMENT SUMMARY

This section summarizes the requirements which Orbital Operations places on the Space Tug/external interfaces The primary intent is to assure all baseline requirements are met and that the specific problems of Orbital Operations are considered in the existing requirements

The requirement number used is the same number used throughout this study and, therefore, has traceability to previous data exchanges and to a baseline document and page The numerical system chosen to identify requirements can be best explained by an example

OTI-1-17-140 (Requirement Example)

In the above example, OTI represents an Orbiter/Tug Interface Requirement Designators used throughout Section 2 0 are

OTI = Orbiter/Tug Interface (Used in Section 2 2 1)
PTI = Payload/Tug Interface (Used in Section 2 2 2)
TGI = Tug/Ground Interface (Used in Section 2 2 3)
TS = Tug System (Used in Section 2 5)

The initial number 1, in our example, is a sequential number which has been arbitrarily assigned to requirements This sequence number can be used to identify a requirement within the IBM numbering sequence system The second number, 17 in our example, is a document identification number which corresponds to the IBM IUS/Tug technical library The MSFC Space Tug Baseline Documents have been assigned the following document identification number

Volume 1 = 10
Volume 2 = 16
Volume 3 = 17
Volume 4 = 15

The third number, 140 is the page in the baseline document where the requirement will be found

2 2 1 Space Tug/Shuttle Orbiter Interface Operational Requirements Assessment

This is a summary of the Space Tug/Shuttle Orbiter Operational Interface Requirements as defined by the baseline documentation This contains the results of their assessment to date and incorporates actions resulting from data exchange meetings

The requirements are categorized into Implemented, Concerns, Implementation Undefined, Deleted and Proposed The category of "Implemented" contains the requirements upon which there is agreement and thus are being implemented With each requirement is a statement elaborating on implementation The category of "Concern" contains the requirements that cannot be or are not being implemented This category consists mainly of conflicting requirements and includes options and recommendations The category of "Implementation Undefined" has reasons given for each requirement so categorized The category "Deleted" consists of those requirements removed because of similarity, duplication and those not directly affecting the operational interface The "Proposed" requirement category contains recommended requirements which became apparent during the assessment of the existing requirements

2 2 1 1 Operational Requirements Implemented

The following requirements are those where there is agreement and, therefore, are being implemented as follows

OTI-1-17-139 The Orbiter/Tug operations interface will be kept to a minimum and standardized

Implementation - This requirement is being met with data bus technology, autonomy II Tug design and Orbiter operations limited essentially to safety and contingency situations

OTI-5-17-141 Capability shall be provided for Orbiter crew to dump hazardous Tug fluids and vent Tug pressurants overboard through the Orbiter vent system with the payload bay either open or closed

Implementation - Any valve is accessable from the keyboard and switches are available for pressure relief

OTI-6-17-140 Tug communications to the ground while in the Orbiter cargo bay shall be by relay of the standard Tug telemetry format through the Orbiter communications system

Implementation - Tug will conform to the standard Orbiter TM format because it is user of that system

OTI-7-17-141 The Tug shall be capable of accepting a state vector and attitude update from the Orbiter prior to release and from the ground when in free flying mode

Implementation - Position and velocity update three hours before injection and or attitude update 15 minutes before injection is planned

OTI-8-16-55 The electrical power system shall be started from the ground with emergency shutdown capability from the Orbiter

Implementation - Tug fuel cells will be activated during prelaunch Stop or start of the electrical power system can be accomplished from the Orbiter aft station switch and via the R F link from either the ground or the Orbiter

OTI-9-10-19 The baseline Tug while in the payload bay shall provide systems status data to and receive commands from, Tug/SC Operations Center(s) via the Orbiter provided communications relay as defined in JSC 07700

Implementation - Status and commands will be exchanged across the Orbiter/Tug interface to/from TOC, however, Orbiter commitment is subject to operational mode control by the crew

OTI-10-10-58 Internal attitude control signal of the Tug shall be capable of being checked for accuracy by the Orbiter crew before release

Implementation - Tug internal attitude control signals will be available at the Aft Display but Orbiter maneuvers must be made to check accuracy

OTI-12-10-70 Spacecraft shall provide caution and warning data to the Orbiter and crew for safety critical functions while aboard or in the near vicinity of the Orbiter

Implementation - The Spacecraft C&W paths to the Orbiter exist both hardwired and as part of the Tug telemetry data

OTI-14-10-65 Positive indications of Tug electrical systems shut down status shall be provided to the Orbiter flight crew, prior to retrieval

Implementation - Verification light on the panel at the Aft Station indicates execution of the command, however, fuel cells are required until after retrieval

OTI-15-10-63 Command affecting safety critical equipment status must have associated data transmission to provide a positive functional verification.

Implementation -Verification light on the panel at the Aft Station indicates execution of the command

OTI-17-10-62 Tug propulsion system start sequence logic status and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management Interface Transmissions shall be through hardware while within the Orbiter bay but once outside it may be transmitted directly from the Tug

Implementation - Propulsion logic status and valve positions will be accessable from keyboard and display This data will be in the Tug telemetry data

OTI-18-10-58 Tug attitude shall be controlled by the Orbiter immediately following release during deployment and before retrieval to preclude possibility of collision Control distance for deployment and retrieval operations is TBD

Implementation - APS will be operative immediately after release from RMS The Tug will hold attitude while the Orbiter maneuvers

OTI-19-10-51 No single Tug failure shall result in a hazard which jeopardizes the flight or ground crews of the Shuttle, general public, public/private property or the ecology

Implementation - Requires dual redundancy and is being implemented

OTI-21-10-62 APS shall be capable of being shut down by one command from the Orbiter

Implementation - APS shut down is possible with switch at Aft Station.

OTI-22-10-20 The Tug (while in the cargo bay) shall relay via the Orbiter, SC operations center control commands as required for mission preparations Orbiter safety related commands to the SC shall be relayed to the SC

Implementation - SC telemetry and command data links are fed thru Tug to and from the Orbiter

OTI-23-10-20 The Tug (while in the cargo bay) shall relay SC systems status data to the Orbiter for relay to SC operations center(s)

SC systems safety data shall be relayed to the Orbiter for caution/warning

Implementation - SC telemetry is fed thru Tug and Orbiter for relay to SCOC SC safety data is relayed thru the Tug to the Orbiter C&W

OTI-24-10-19 The Tug shall have the capability to accept changes in mission assignment (not including SC changeout), target or SC ephermeris up to within two hours prior to launch

Implementation - Requires memory reload and verify within two hours which is planned

OTI-25-10-19 The baseline Tug while in the payload bay and during Tug/SC/Orbiter deployment/retrieval operations shall provide safety critical status data to, and receive overriding corrective commands or safing commands from, the Orbiter and Tug/SC Operations Center(s) The system shall be compatible with the standard Orbiter warning displays and devices. Tug Operations Center will provide back-up monitoring and command of all safety functions Normal Tug operations shall not require controls in the Orbiter except for (1) emergency safing, (2) safety interlocks, (3) deployment and retrieval operations, and (4) activation/deactivation There is no requirement for Orbiter/Tug communications following deployment operations until Tug/Orbiter rendezvous and retrieval operations begin

Implementation - The requirement to monitor and allow override of safety items is implemented with Orbiter prime and TOC back-up

OTI-26-10-19 The Tug shall provide flight program memory verification data to and receive memory load updates from the Tug operations center via relay by the Orbiter while in the Orbiter payload bay

Implementation - Memory reload and verify thru Orbiter is planned

OTI-28-10-28 After physical separation from the Orbiter, the Tug shall maintain a stable attitude consistent with Orbiter deployment mechanism tipoff rates until a safe Orbiter-Tug separation distance and confirmed mission readiness have been accomplished

Implementation - APS will be operative immediately after release from RMS The Tug will hold attitude while the Orbiter maneuvers.

OTI-30-10-45 Mission critical single failure points will be minimized to the maximum extent possible

Implementation - Mission critical single failure points will be minimized as a goal

OTI-32-10-20 The Tug shall be capable of receiving secure commands from and transmitting secure data to the Orbiter and Tug/SC operations center(s) The Tug shall be capable of transmitting commands

to the Spacecraft and receiving data from the Spacecraft The communications system shall be Space Ground Link System (SGLS) compatible and shall permit encryption-decryption capability

Implementation - SC telemetry and command data links are fed thru Tug to and from the Orbiter, are SGLS compatible and permit encryption and decryption

OTI-33-10-21 Electrical power for Tug/SC is available from the Orbiter electrical power system An electrical energy allowance of 50 kilowatt-hours (kwh) is dedicated for Tug/SC support with energy in excess of this allocation being mission dependent and capable of being supplemented by additional consumables to the Orbiter fuel cells and/or by independent Spacecraft systems This power is in the form of regulated redundant 28 V DC Power levels and regulation shall be as specified in JSC 07700 Volume XIV

Implementation - Electrical power for Orbiter to Tug is being utilized and will require power transfer prior to deployment operations of the Tug and the Spacecraft

OTI-35-10-46 Isolation of anomalies of mission and crew essential functions will be provided to assure a failure will not propagate across any interface During ground operations, capability to fault isolate to the line replaceable unit (or group of units) without disconnections or use of carry-on equipment, shall be provided

Implementation - Isolation of anomalies to prevent crossing interfaces and to LRU must be treated as a goal

OTI-36-10-54 All mechanical, electrical and fluid connections between the Tug and Spacecraft and Orbiter shall be fail safe

Implementation - Dual redundancy is being implemented

OTI-37-10-54 Provisions shall be made to confirm that all safety critical Orbiter/Tug electrical connections, fluid lines, etc , interfaces are securely connected

Implementation - Interlocks on all safety critical interfaces are being implemented

OTI-38-10-54 No single failure shall result in unprogrammed motion of the Tug while aboard the Orbiter, during deployment within TBD distance of the Orbiter, or during retrieval of the Tug

Implementation - Dual redundancy in Flight Control System hardware is being implemented

OTI-39-10-54 As a minimum, Tug shall be designed to sustain a failure and retain the capability to successfully terminate the Tug functions

without injuring flight personnel or damaging the Orbiter or other payloads (fail-safe)

Implementation - This requires dual redundancy which is being implemented

OTI-40-10-54 Tug operations and energy levels shall be held to a minimum while aboard or in the near vicinity of the Orbiter

Implementation - Operations and energy levels are being held to a minimum as a goal

OTI-42-10-62 Interlocks shall be provided to assure that propulsion systems will not be fired while in the Orbiter payload bay and that no single operation shall result in propellants being dumped in the payload bay

Implementation - Propulsion will be interlocked safe with power buses controlled by switches at the Aft Station

OTI-43-10-63 Message signals for Tug system, by hardwire and RF telemetry, shall be provided at the Shuttle Data Management System Interface Measurements shall include Tug latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications This information should also be available prior to retrieval

Implementaion - Data requested is being provided by a combination of C&W display and keyboard/display Data is provided by a combination of hardwire and as part of the Tug telemetry data

OTI-57-10-70 Provisions shall be made to confirm that all safety critical Spacecraft/Tug interfaces are securely connected prior to retrieval of Tug

Implementation - Spacecraft/Tug interfaces are interlocked and summarized as a C&W displayed parameter

OTI-62-10-75 RF communcation capability shall be available between the Orbiter and the Spacecraft for safety related command and control functions while detached from the Orbiter and up to a separation distance of TBD

Implementation - There will be communications capability between the Orbiter and the Spacecraft (via the Tug) for safety related command and control while attached, detached from the Orbiter, up to a separation distance of 20 NM

OTI-64-10-75 Automatic event sequencing programs and automatic controls whose actuation could affect flight personnel safety shall be operative only by the Orbiter, or by ground control enabling switches (command over-ride), e g , pyrotechnic sequences, automatic deployment sequences, etc

Implementation - Orbiter prime and ground back-up control of safety items is provided

2 2 1 2 Operational Requirements Concerns, Options and Recommendations

The following requirements are those which can not be or are not being implemented With each stated requirement is given the reason for concern, the options to alleviate the concern and the recommendation to close out the issue

Requirement No 2 and 29

QTI-2-17-139 A Tug automatic caution and warning system will be provided to alert the Orbiter to hazardous conditions in the Tug when attached or within TBD miles of the Orbiter This system shall interface with the standard Orbiter caution and warning displays and warning devices

OTI-29-10-45 (1) All subsystems except primary structure and pressure vessels shall be designed to fail safe in the vicinity of the Shuttle Oribter

(2) All safety subsystems shall be designed to fail operational in the vicinity of the Shuttle Orbiter

- Concern

  - Detached Tug C&W data flow path is simplex at Orbiter Payload Data Interleaver as presently defined

- Options

  - Orbiter design change to implement redundant data paths thru Payload Data Interleaver

  - Procedural change to implement an Orbiter evasive maneuver to safe distance and ground activation, checkout of Tug/Spacecraft

  If checkout OK then proceed with mission

  If checkout not OK then ground will safe Tug/Spacecraft and Orbiter will retrieve Tug/Spacecraft if possible.

- Recommendation

  - Procedural change provides satisfactory technical solution

Requirement No 3

OTI-3-17-140 Design Tug so it can be jettisoned in orbit by command from Orbiter or ground for emergency reasons Provide emergency deploy and release of Tug to Orbiter connections

- Concerns
  - Currently not in baseline design
  - IBM/GDC-I/MSFC have discussed issue and have assumed jettison equates to normal Tug deployment
  - What is minimum deploy time for emergency conditions?
  - Are there Tug system failures which can manifest themselves prior to the minimum deploy time?
- Recommendations
  - JSC/MSFC should define minimum deploy time for emergency conditions
  - Space Tug studies should define system failures that could occur prior to minimum time and design protection against identified failures

  Or

  - Delete Requirement No 3

Requirement No. 20

OTI-20-10-51 The proper functioning of the interface between the STS and Tug shall be maintained under all nominal, contingency, and emergency operations of either the STS or the Tug

- Concern
  - Detached Tug data flow path is simplex at Orbiter Payload Data Interleaver
- Options
  - Orbiter design change to implement redundant data paths thru Payload Data Interleaver
  - Procedural change (same as Requirement No 2 and 29)
- Recommendation
  - Procedural change (same as Requirement No 2 and 29)

Requirement No 27

OTI-27-10-28 The Tug shall not initiate its propulsion system until a safe separation distance and attitude relationship between Orbiter and Tug is achieved The Tug propulsion system shall not cause impingement of exhaust gases that would be harmful to the Orbiter

- Concerns
  - APS will be activated shortly after physical deployment
  - It is assumed the requirement statement is applicable to main propulsion system only
- Recommendations
  - Restate requirement for application to main propulsion system only

Requirement No 44

OTI-44-10-63 Tug critical command and control circuitry shall be designed to be fail operational/fail safe as a minimum

- Concerns
  - Requirement statement for fail operational/fail safe stated in MSFC Baseline document
  - First Data Exchange recommendation was stated as "No Single Point Failure Shall Result in a Hazard which Jeopardizes the Flight or Ground Crew"
  - No indication of fail safe design in Avionics or operational interface
- Recommendation
  - MSFC needs to restate current requirement for contractor guidance

Requirement No 45

OTI-45-10-63 Tug autonomous navigation commands for attitude control and translation maneuvers shall be disabled until a safe separation distance and compatible trajectories can be verified

- Concerns
  - APS (attitude hold) will be activated shortly after physical deployment

- Requirement statement implies no commands for attitude holds

- Recommendation

  - Restate requirement to exclude attitude hold activation

2 2 1 3 Operational Requirements Implementation Undefined

The following requirements are those which implementation is not currently defined

OTI-4-17-141 Provision shall be made to redump any recorded data in the event that a data dump is unsuccessful

Assessment - This requires a recorder with replay feature or loop and confirm receipt before erase feature This is undefined

OTI-11-10-70 Any Spacecraft subsystem operation which impacts safety during the launch and entry phases shall be monitored via C&W (caution and warning) and controlled from the Orbiter flight station

Assessment - Spacecraft C&W is defined as 35 functions and crew control is defined as 94 discretes, however, operational details of what is displayed and controlled is not defined

OTI-34-10-22 The Tug shall be compatible with all Shuttle abort modes and procedures specified in JSC 07700, Volumn X and XIV

Assessment - Tug compatibility with very limited definition of Shuttle abort modes cannot be fully defined

OTI-60-10-75 Spacecraft propulsion system start sequence logic status, and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management System interface The transmission shall be through Tug hardware while within the payload bay but once outside it may be transmitted either directly from the Spacecraft or via the Tug telemetry system

Assessment - The Spacecraft two-way communication path with the Orbiter exists, message signal content detail is undefined

OTI-61-10-75 Message signals from Spacecraft systems shall be provided at the Shuttle Data Management System Interface Measurements shall include at least Spacecraft latched/released indication, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications

Assessment - The Spacecraft two-way communication path with the Orbiter exists, message signal content detail is undefined A C&W light is allocated to Spacecraft latch and deploy mechanism called "Spacecraft Arm/Safe".

2 2 1 4 Operational Requirements Deleted

The following 18 requirement numbers are those which have been deleted from further consideration because most are operationally duplicates or have no impact on operational functions See Appendix A Section 1 0 for requirement statements and reasons for deletion

DELETED REQUIREMENT NUMBERS

OTI-13-10-66	OTI-48-10-64	OTI-54-10-65
OTI-16-10-63	OTI-49-10-64	OTI-55-10-65
OTI-31-10-45	OTI-50-10-64	OTI-56-10-71
OTI-41-10-61	OTI-51-10-64	OTI-58-10-74
OTI-46-10-63	OTI-52-10-64	OTI-59-10-74
OTI-47-10-64	OTI-53-10-64	OTI-63-10-77

2 2 1 5 Operational Requirements Proposed

The following requirements have been defined from the analysis of the Space Tug operations and are proposed to be added to the baseline.

1 System Level Checkout Requirement

Consistent with Level II autonomy Tug design baseline and with the state-of-the-are in Built-in-Test-Equipment (BITE), it is a Tug requirement to be primarily responsible for system level checkout as part of redundancy management The Tug Operations Center (TOC) will be primarily responsible for detailed status keeping

2 Classified Payloads

In the event a classified payload is retrieved it may be desirable to remove part or all of it from the Tug while in the cargo bay Some form of requirement will be necessary to handle such a situation. In general, no requirement addresses just what the Orbiter is to do with classified payloads

This situation could impact mission planning if the Tug were ever required to deploy an unclassified but retrieve a classified payload

2 2 2 Space Tug/Spacecraft Interface Operational Requirements Assessment

This is a summary of the Spacecraft/Tug operational interface requirements as defined by the baseline documentation The following paragraphs contain the results of this assessment and incorporate actions resulting from data

exchange meetings The requirements are categorized into Implemented, Deleted and Exceptions The category of "Implemented" contains the requirements upon which there is agreement and thus are being implemented In some cases, however, there is not a total operational definition possible from available companion studies With each requirement is a statement elaborating the implementation The category of "Deleted" consists of those requirements removed because of similarity, duplication and those not directly effecting the operational interface. The "Exception" category consists of those requirements where there is not agreement and exception is being taken Rationale is given for the exception

2 2 2 1 Operational Requirements Implemented

The following are requirements where there is agreement and, therefore, are being implemented as stated

PTI-1-17-140 Capability shall exist for ground initiation of all control signals to the SC interface

Implementation - The ground can, through the Orbiter and/or Tug 2 KBPS command uplink, initiate any control signals to the SC interface.

PTI-2-10-70 Provisions shall be made to confirm that all safety critical Spacecraft/Tug interfaces are securely connected prior to retrieval of Tug

Implementation - Spacecraft arm/safe is displayed on the Orbiter C&W panel

PTI-3-10-38 The Spacecraft will have its own checkout system

Implementation - The Spacecraft will do a complete self test and report results through the Tug and Orbiter (if in the bay) to the ground

PTI-4-10-20 The Tug shall provide limited sequencing as required to the SC prior to Tug/SC separation

Implementation - The Tug will provide identified operational sequencing of the Spacecraft prior to Tug/SC separation

PTI-6-10-16 SC location, initialization, spin-up and release are performed automatically Prior to deployment, Tug monitors go/no go SC status and thruputs SC telemetry to the ground

Implementation - The Tug is planned to provide these required services to the Spacecraft

PTI-7-10-20 The Tug shall be capable of receiving secure commands from and transmitting secure data to the Orbiter and Tug/SC operations center(s) The Tug shall be capable of transmitting commands to the Spacecraft and receiving data from the Spacecraft The communications system shall be Space Ground Link

Systems (SGLS) compatible and shall permit encryption-decryption capability

Implementation - The Tug will provide two-way communication between SC and Tug/SC operation centers It will be Space Ground Link Systems (SGLS) compatible with encryption-decryption capability

PTI-8-10-20 The data link between Tug and SC during any part of the mission shall be by hardline only

Implementation - There are only hardwire links between the SC and the Tug, no RF link is planned

PTI-9-10-20 The Tug shall relay SC systems status data to the Orbiter for relay to SC operations center(s) SC systems safety data shall be relayed to the Orbiter for caution/warning

Implementation - SC system status is relayed thru the Tug and Orbiter to SCOC SC system safety data is relayed to Orbiter C&W

PTI-11-10-21 The Tug shall provide to the SC (single or multiple) 300 to 600 watts of 28 volts DC electric power during the Tug/SC orbit transfer phase. The total electric energy shall be TBD. SC requirements for electric power other than 28 VDC shall be provided by the SC.

Implementation - Tug is providing power to the SC This requires a power transfer prior to SC deploy and effects Tug/SC interface.

PTI-12-10-21 Electrical power for Tug/SC is available from the Orbiter electrical power system An electrical energy allowance of 50 kilowatt-hours (Kwh) is dedicated for Tug/SC support with energy in excess of this allocation being mission dependent and capable of being supplemented by additional consumables to the Orbiter fuel cells and/or by independent Spacecraft systems This power is in the form of regulated redundant 28 V DC Power levels and regulation shall be as specified in JSC 07700 Volume XIV

Implementation - Orbiter is providing power to Tug and SC This, similar to No 11, again requires a power transfer prior to SC deploy and effects Tug/SC interface

PTI-13-10-38 Critical and hazardous Tug and Spacecraft checkout systems and functions will be controlled through Orbiter interface(s)

Implementation - Orbiter control is required for critical and hazardous SC checkout systems and functions The SC has stated 94 discretes are required at the Tug/SC interface and that some are Orbiter controlled but no operational detail exists

PTI-14-10-45 All subsystems except primary structure and pressure vessels shall be designed to fail safe in the vicinity of the Shuttle Orbiter All safety subsystems shall be designed to fail operational in the vicinity of the Shuttle Orbiter

Implementation - Requires fail operational design of Tug/SC interface which is being implemented with a redundant design

PTI-20-10-70 Spacecraft shall provide caution and warning data to the Orbiter and crew for safety critical functions while aboard or in the near vicinity of the Orbiter

Implementation - This differs from No 9 by adding the requirement to provide SC C&W data to Orbiter while in the vicinity of the Orbiter The Tug telemetry data is radiated to the Orbiter while in the vicinity and contains SC C&W data

PTI-30-10-78 The arming of pyrotechnic devices shall be protected against accidental operations

Implementation - The arming of pyrotechnic devices will be done just prior to use They will be interlocked while in the cargo bay and in the vicinity of the Orbiter Status of interlocks will be available to the Orbiter

PTI-32-10-78 Sequence logic and pyrotechnic firing circuits shall be at least dual redundant

Implementation - Interface sequencing logic and pyrotechnic firing circuits are defined as redundant

PTI-33-10-79 Provisions shall be made for safing on command unused explosive devices aboard the Spacecraft and safing verification sent to the orbiter prior to retrieval

Implementation - Interface design is planned to provide the above

PTI-34-10-75 Message signals from Spacecraft systems shall be provided at the Shuttle Data Management System interface Measurements shall include at least Spacecraft latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and presure measurements, and failure indications

Implementation - SC status will be relayed thru the Tug to the Orbiter Thru the telemetry system it will be available for display in the Orbiter To call out specifically that all of these operational measurements will be available is beyond the level of detail available at this time.

PTI-35-10-75 RF communication capability shall be available betwen the Orbiter and the Spacecraft for safety related command and control functions while detached from the Orbiter and up to a separation distance of TBD

Implementation - There will be communications capability between the Orbiter and the Spacecraft (via the Tug) for safety related command and control while

attached, detached from the Orbiter, up to a separation distance of 20 NM.

PTI-36-10-75 Automatic event sequencing programs and automatic controls whose actuation could affect flight personnel safety shall be operative only by the Orbiter, or by ground control enabling switches (command over-ride), e g , pyrotechnic sequences, automatic deployment sequences, etc

Implementation - Actuation of items which effect personnel safety will be interlocked and enabled only by Orbiter or by ground control when conditions are safe

PTI-37-10-75 Commands affecting safety critical equipment status must have associated data transmission to provide a positive functional verification.

Implementation - Commands affecting safety critical status have feedback transmitted to indicate functional verification

PTI-38-10-75 Spacecraft propulsion system start sequence logic status, and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management System interface The transmission shall be through Tug hardware while within the payload bay but once outside it may be transmitted either directly from the Spacecraft or via the Tug telemetry system

Implementation - Spacecraft propulsion start logic and valve positions will be available via telemetry and Orbiter display The transmission will be via Tug or direct from Spacecraft

2.2 2 2 Operational Requirement Exception

The following is a requirement where there is not agreement and exception is taken Rationale is given for the exception

- Requirement from Baseline System Requirements and Guidelines Volumes 1, Paragraph 3 2 6 2.3 d (8)

PTI-39-10-75 Spacecraft autonomous navigation commands for attitude control and translation maneuvers shall be disabled until a safe separation distance (TBD) from the Tug and compatible trajectories can be verified

Rationale - Attitude control must be enabled immediately after deploy to hold attitude and minimize tip off rates

2 2.2 3 Operational Requirements, Deleted

The following 21 requirement numbers are those which have been deleted from further consideration because most are operationally duplicate or have no impact on operational functions. See Appendix A Section 2.0 for requirement statements and reasons for deletion

DELETED REQUIREMENTS NUMBERS

PTI-5-10-20	PTI-21-10-70	PTI-28-10-77
PTI-10-10-20	PTI-22-10-61	PTI-29-10-78
PTI-15-10-45	PTI-23-10-64	PTI-31-10-78
PTI-16-10-45	PTI-24-10-64	PTI-40-10-74
PTI-17-10-46	PTI-25-10-64	PTI-41-10-74
PTI-18-10-54	PTI-26-10-64	PTI-42-10-71
PTI-19-10-70	PTI-27-10-76	PTI-43-10-71

2 2.3 Space Tug/Ground Control Interface Operational Requirements Assessment

This is a summary of the Space Tug/Ground Control Operational Interface Requirements as defined by the baseline documentation The following paragraphs contain the results of this assessment and incorporate actions resulting from data exchange meetings The requirements are categorized into Implemented, Deleted and Exceptions The category of "Implemented" contains the requirements upon which there is agreement and thus are being implemented In some cases, however, there is not a total operational definition available from companion studies With each requirement is a statement elaborating the implementation The category of "Deleted" consists of those requirements removed because of similarity, duplication and those not directly effecting the operational interface The "Exception" category consists of those requirements where there is not agreement and exception is being taken Rationale is given for the exception

2 2 3 1 Operational Requirements Implemented

The following are requirements where there is agreement and, therefore, are being implemented as stated

TGI-1-17-40 Tug flight operations shall be compatible with NASA operation requirements and concepts for Tug (NASA Tug Operations Concept Document - TBD)

Implementation - The document is TBD because this study is originating a recommended plan and will be, therefore, compatible

TGI-2-17-122 The Tug Operations Center will have the capability to initiate Tug safing prior to Orbiter capture

Implementation - The TOC will command the initiation of Tug safing prior to Orbiter Retrieval

TGI-3-17-112 The Orbiter crew will perform the Tug propellant dump required for any mission abort prior to Tug release Backup command capability will be from ground control

Implementation The Orbiter crew will initiate Tug propellant dump with the TOC as backup.

TGI-4-17-139 A Tug automatic caution and warning system will be provided to alert the Orbiter to hazardous conditions in the Tug when attached or within TBD miles of the Orbiter This system shall interface with the standard Orbiter caution and warning displays and warning devices. Ground control will provide backup monitoring of all crew safety functions

Implementation - The ground (TOC) is prime evaluator of Tug detailed status, therefore, it is backup monitoring all crew safety functions

TGI-9-10-58 Tug propellant tank integrity shall be verified, pressures and hazardous fluid quantities shall be reduced to a safe value, and ordnance circuits shall be safed before Tug retrieval operations begin

Implementation - The ground is prime in maintaining detailed Tug status at all times and will provide this verification

TGI-10-10-31 The Tug shall be capable of performing, within the mission durations of Paragraph 3 2 1 1 C, Baseline Volume 1, post deployment visual inspections of SC to insure SC mission preparations are adequate

Implementation - The Tug will perform a visual inspection of the deployment Spacecraft via the Tug TV monitor and relay data to the ground to insure Spacecraft mission preparations are adequate

TGI-11-10-29 The Tug/SC shall be placed in a safe condition and verified by Tug operations center prior to reaching the minimum safe distance of TBD prior to docking with the Orbiter

Implementation - The ground is prime in monitoring detailed Tug status at all times

TGI-15-10-16 Tug Telemetry (Downlink) will provide secure events and analog parameters when stored limits exceeded

Implementation - The ground is prime in monitoring detailed Tug status at all times and will record anomalies

TGI-16-10-16 Redundancy Management and systems update will provide subsystem control, fault isolation, redundancy management, switchover by onboard checkout and fault isolation. Secure command override for burn, abort and alt mission(s) cancellation (single mode word command(s)) Status secure downlinked for ground monitor. Secure command to load memory module(s) (i e , R MGT , diagnostic T/shooting and overrides).

Implementation - The ground is prime in monitoring secure detailed Tug status at all times and has backup secure override capability

TGI-17-10-16 Alternate mission determination and selection will be by ground option and initiated from the ground by secure uplink

Implementation - The ground will have the capability of determining and effecting an alternate Tug mission via a secure uplink

TGI-18-10-16 SC rendezvous will be automatically accomplished by terminal phase guidance with the target passive The ground will provide event telemetry monitoring

Implementation - The ground is prime evaluator of detailed Tug status Therefore, SC rendezvous events are telemetered to the ground

TGI-19-10-16 SC deployment monitor, location, initialization, spin-up and release will be performed automatically Prior to deployment, Tug monitors go/no go SC status and thruputs SC telemetry to the ground

Implementation - The ground is prime evaluator of Tug detailed status While SC is attached to the Tug, Tug telemetry contains SC data

TGI-20-10-16 SC docking will be accomplished automatically with target passive or not actively evasive The ground will provide event telemetry secure monitoring

Implementation - The ground is prime evaluator of Tug detailed status Therefore, SC docking events are telemetered to the ground

TGI-21-10-20 The Tug shall be capable of receiving secure commands from and transmitting secure data to the Orbiter and Tug/SC operations center(s) The Tug shall be capable of transmitting commands to the Spacecraft and receiving data from the Spacecraft The communications system shall be Space Ground Link Systems (SGLS) compatible and shall permit encryption-decryption capability

Implementation - The Tug is capable of receiving secure commands from and transmitting secure data to the Tug/SC operations centers either thru the Orbiter while attached or directly while free flying The Tug forwards data to/from the SC while they are attached Communications will be SGLS compatible and have encryption-decryption capability

TGI-22-10-22 The Tug shall be compatible with all Shuttle abort modes and procedure specified in JSC 07700, Volume X and XIV

Implementation - The Tug/Ground compatibility with very limited definition of Shuttle abort modes can not be fully defined

TGI-24-10-29 The Tug shall provide the capability to respond to backup or corrective commands from the Orbiter or mission operations for off-nominal deployment functions

Implementation - The ground is prime evaluator of detailed Tug status, therefore, will be aware of off-nominal deployment functions The Tug will have the capability to respond to backup or corrective commands from the TOC

TGI-25-10-29 The Tug shall be capable of being jettisoned in orbit by command from Orbiter or ground for emergency reasons Provide emergency manual deploy of Tug as backup.

Implementation - The ground is prime evaluator of detailed Tug status, therefore, will be aware of off-nominal deployment requirements The TOC will backup Orbiter commanding of Tug jettison functions The Tug will have the capability to respond to backup or corrective commands for TOC.

TGI-33-10-54 No single failure shall result in unprogrammed motion of the Tug while aboard the Orbiter, during deployment within TBD distance of the Orbiter, or during retrieval of the Tug

Implementation - The ground is always backup to the Orbiter for safety critical functions, therefore, can not effect the Tug without Orbiter permission Therefore, no single point failure exists operationally at the ground/Tug interface

TGI-34-10-60 A capability for remotely controlled expulsion of Tug main propellant tank residuals to space before retrieval operations and pressurization with inert gases be provided.

Implementation - The Tug will automatically safe main propellants, however, the ground and Orbiter will backup the command if required

TGI-35-10-63 Commands affecting safety critical equipment status must have associated data transmission to provide a positive functional verification

Implementation - Positive functional verification will be available in the form of telemetry response to commanded uplink

2 2 3 2 Operational Requirements Exceptions

The following are requirements, where there is not agreement and exceptions are taken Rationale is given for the exceptions

- Requirement from Baseline System Requirements and Guidelines, Volume 1, Paragraph 3 1 3 2

TGI-5-10-12 Ground Firing of Tug Main Engine - Within orbit phasing requirements, and with all systems enabled and prepared, the Tug acquires the proper vector and the main engine is fired from the ground as necessary to achieve the desired Spacecraft orbit or trajectory insertion conditions (or retrieval conditions for a retrieve-only mission)

Rationale - The ground command for main engine burn is only a backup (contingency) for autonomy Level II which is baseline This is a normal function performed by the Tug on-board computer

- Requirement from Baseline System Requirements and Guidelines, Volume 1, Paragraph 3 2 6 1 4 C (4)

TGI-6-10-63 Tug APS and Translation Maneuvers Disabled at Deploy - Tug autonomous navigation commands for attitude control and translation maneuvers shall be disabled until a safe separation distance and compatible trajectories can be verified

Rationale - Attitude control must be enabled immediately after deploy to attitude hold and minimize tip off rates

- Requirements from Baseline System Requirement and Guidelines, Volume 1, Paragraph 3 2 1 1 G.

TGI-12-10-15 Tug Compatible with NASA STDN/TDRS and AF SGLS/SCF Communications and Tracking Systems - The baseline Tug shall be compatible with the NASA STDN/TDRS and the AF SGLS/SCF communications and tracking systems

Rationale - Tug system defined for Level II Autonomy has no tracking requirement with the addition of the Interferometric Landmark Tracker

- Requirement from Baseline System Requirements and Guidelines, Volume 1, Figure 4

TGI-13-10-16 Post Separation Activation Sequence - Automatic - (After secure RF uplink from ground to initiate)

Rationale - Tug activation is automatic for an Autonomy Level II Tug except for contingency

- Requirements from Baseline System Requirements and Guidelines, Volume 1, Figure 4

TGI-14-10-16 Orbital Tracking - TDRS and DSN

Rationale - There is no tracking requirement for a Tug system designed for Autonomy Level II

- Requirements from Baseline System Requirements and Guidelines, Volume 1, Paragraph 3.2.1 2 1 4

TGI-23-10-28 Deployment, Ground Confirmation of Mission Readiness - After physical separation from the Orbiter, the Tug shall maintain a stable attitude consistent with Orbiter deployment mechanism tipoff rates until a safe Orbiter-Tug separation distance and confirmed mission readiness have been accomplished

Rationale - Consistent with Level II Autonomy, the mission will proceed automatically unless halted by ground intervention due to an identified contingency.

2 2 3 3 Operational Requirements Deleted

The following 9 requirement numbers are those which have been deleted from further consideration because most are operationally duplicates or have no

impact on operational functions See Appendix A Section 3 0 for requirement statements and reasons for deletion

DELETED REQUIREMENTS NUMBERS

TGI-7-10-58	TGI-27-10-45	TGI-30-10-51
TGI-8-10-58	TGI-28-10-46	TGI-31-10-54
TGI-26-10-45	TGI-29-10-51	TGI-32-10-54

2 3 SPACE TUG ORBITAL CHECKOUT REQUIREMENTS ASSESSMENT SUMMARY

This is a summary of the Space Tug Orbital checkout baseline requirements assessment The following paragraphs contain results of their assessment and incorporate action resulting from data exchange meetings. The requirements are categorized into two main areas: Implemented and Exceptions. The category of Implemented is further divided or allocated to the responsible operational element The implemented and allocated requirements are those where there is agreement and therefore are being utilized as a basis for Space Tug orbital checkout The category of Exceptions consists of those requirements where there is not agreement and exception is being taken Rationale is given for the exception.

2 3 1 Operational Requirements Implemented and Allocated

The following requirements are those where there is agreement and therefore are being implemented They are allocated as to prime and back-up responsibilities to enable specific definitions and sizing of operational impact

- Shuttle Prime Responsibilities
  - Shuttle will monitor Tug/Spacecraft systems during all flight phases while in Cargo Bay
  - Shuttle will hold Tug APS inhibited till after release by RMS. Shuttle will enable TUG APS
  - Shuttle will disable Tug APS prior to retrieval or for mission termination
  - Shuttle will monitor TUG/SC crew safety related parameters while they are in near vicinity.
  - For Mission abort, crew will initiate and monitor Tug propellant dump prior to Tug release.
  - Shuttle will monitor Tug/SC systems to ensure safe condition through landing
- Shuttle Back-up Responsibilities
  - Shuttle crew will support (upon ground request) pre-deploy C/O

- Ground Control Prime Responsibilities
  - Ground controllers will verify readiness of Tug/SC for deploy based on monitoring Tug/SC systems.
  - Ground Controllers will verify readiness of Tug/SC for retrieval based on monitoring Tug/SC systems
  - Ground controllers will maintain detailed status of Tug/SC systems for entire mission.
- Ground Control Back-up Responsibilities
  - Ground control will provide back-up control of crew safety functions.
- Tug Prime Responsibilities
  - Redundancy Management will be done by Tug
  - Forward go/no-go from SC C/O to TOC

2 3 2 Operational Requirements Exceptions

The Space Tug orbital checkout baseline requirements were reviewed to determine any potential requirement conflicts with projected design or operations philosophies The exceptions are as noted with rationale given for each

- Requirement Excerpt from Baseline Flight Operations, Volume 3, Paragraph 3 6.1

  Tug/Spacecraft Monitoring and Checkout by the Shuttle

  "The Shuttle must checkout and activate the Tug attitude hold systems prior to remote manipulator system (RMS) release, and inhibit the APS until after release is accomplished "

Rationale - APS will not be checked out prior to use, system consists of series of valves which will be status monitored when used

- Requirement Excerpt from Baseline Flight Operations, Volume 3, Paragraph 4 3 1 4

  Tug/SC Deploy

  "They will then remove the Tug/SC from the bay and deploy it to the release position. Then under control of the crew and monitored by the crew and the ground, the Tug will be prepared for release After ground acquisition of Tug signal, and upon receiving affirmation of correct configuration from the ground, the crew will release the Tug and stow the manipulator(s) "

Rationale - Ground acquisition of Tug signal before release from RMS will not be affirmed

Deploy lighting, antenna pointing and Orbiter interface constraints make exception necessary

2 4 SPACE TUG SAFETY CRITICAL OPERATIONAL REQUIREMENTS ASSESSMENT

The Space Tug mission requires an unmanned, powered stage be operating in the vicinity of the manned Space Shuttle Orbiter Safety is therefore a prime consideration in Orbital Operations The following paragraphs identify the goals, the definitions used, the groundrules and the documentation reviewed Next, in Section 2 4 2 is the requirements assessment summary In it is each of the more specific safety requirements assessed along with a statement of operational implementation Section 2 4 3 ends this analysis with a C&W status measurements and annunciators recommendation.

2.4 1 Task Description

The goals of this analysis are defined as follows.

- To identify safety critical functions to eliminate or give sufficient warning of potential hazard due to failure of the Tug operational system
- To assure proper consideration is given to safety in mission operational timelines
- To assure proper consideration is given to safety at Orbiter/Tug operational interfaces

Definitions

The definitions used were

- Safety Critical Functions - those which operationally, through malfunction, could be a hazard to people, property or the ecology.
- Hazard - types of most concern here are burst caused by pressure, collision, and electrical shock

Groundrules

The groundrules used were

- Items identified for C&W display are Safety Critical Functions
- Implementation of hardware, software or procedures required to satisfy Safety Requirements will not result in a hazardous condition.

Documentaion Reviewed

The following documentation was used in this assessment

- Tug Baseline Document Volumes 1-4, 7/74
  - Safety Requirements
  - System Configuration
- Payload Safety Requirement for National Space Transportation System, 7/74
- Concurrent Tug studies data exchange packages
  - Ground Operations Study
  - Payloads Study
  - Avionic Study
  - Interface Study
- IBM Mission Modular Timelines

2,4 2 TUG SAFETY CRITICAL OPERATIONAL REQUIREMENTS ASSESSMENT SUMMARY

Many safety statements are by necessity very broad As such, however, they are difficult to assess and report an impact and show implementation The more specific safety requirements which had an impact on orbital operations were therefore summarized It is possible to trace the requirements to a page in Volume 1 of the Tug Baseline Requirements by using the last two digits of the number of each requirement The operational implementation is designated (OI) Redundant requirements are addressed only once

General

1-5 The proper functioning of the interface between the STS and Tug shall be maintained under all nominal, contingency, and emergency operations of either the STS or the Tug

(OI) The Orbiter/Tug interface is redundant for Safety Critical Functions

2-51 No single Tug failure shall result in a hazard which jeopardizes the flight or ground crews of the Shuttle, general public, public/private property and the ecology

(OI) Potential failures creating hazards are precluded with redundant techniques.

3-53 Tug shall provide at all times the Orbiter such information as necessary concerning the status or condition of Tug and Spacecraft systems to ensure safety of Orbiter and crew Provisions shall also be made for Orbiter override of safety critical Tug and Spacecraft functions during stowage aboard the Orbiter and during Tug deployment and retrieval phases of operations

(OI) The Tug and Spacecraft will provide hardwired C&W and safety critical parameters to the Orbiter while attached After deployment and prior to retrieval, the C&W and safety critical parameters will be provided to the Orbiter via an RF link

4-53 Provisions shall be included for control of all safety critical Tug functions, including attitude and translational position control by Orbiter crew during post-deployment and pre-retrieval operation for Orbiter/Tug separation distances TBD

(OI) Same requirement as previous but expanded to require RF interface with Orbiter crew to allow limited Tug attitude and translational position control of Tug during post-deployment and pre-retrieval up to 20 NM separation

5-54 Provisions shall be made to confirm that all safety critical Orbiter/Tug electrical connections, fluid lines, etc interfaces are securely connected

(OI) Interlock signals are provided to the Orbiter for each interfacing cable or fluid line

6-64 No single failure shall result in unprogrammed motion of the Tug while aboard the Orbiter, during deployment within TBD distance of the Orbiter, or during retrieval of the Tug

(OI) All controls in series with Tug motion will be redundant

7-54 Tug propellants and pressurants shall be reduced to a predetermined safe level prior to Tug retrieval

(OI) The Tug main propulsion system will be dumped and vented prior to rendezvous and retrieval by the Orbiter

8-54 Tug deploy/release/retract mechanisms shall not cause a hazard even after a failure has been experienced with that system(s)

(OI) Failure indications will be issued for Tug deploy/release/retract mechanism

9-54 Provisions must be made for verifying readiness of safety critical Tug systems before total activation of Tug

(OI) C&W parameters will be monitored continuously by the Orbiter (and ground) All safety critical Tug parameters will be checked and verified during Tug activation and checkout in the Orbiter

10-54 Main propellant dump capability shall be available from propellant servicing through the mission, including abort

(OI) Although main propellant dump capability is available by hardwire or uplink during both attached and detached modes, operational requirements will preclude dumps during certain periods, such as deployment and retrieval phases

Operational

11-58 Propellant tank pressures where practical shall not be increased to operational values until TBD distance from the Orbiter after deployment

(OI) Tug main propulsion system will be activated only when the Orbiter is a safe distance (TBD) from the Orbiter

12-58 Tug attitude shall be controlled by the Orbiter immediately following release during deployment and before retrieval to preclude possibility of collision Control distance for deployment and retrieval operations is TBD

(OI) Tug APS will be activated immediately after deployment and deactivated upon retrieval RF command capability will be available from deployment until retrieval (when the Tug is within 20NM of the Orbiter)

13-58 Tug shall be switched from command control to internal attitude control after Orbiter has been sufficiently moved (TBD) so that no Tug attitude change could result in collision with the Orbiter.

(OI) Tug must receive release indication and begin internal attitude control immediately either by internal signal or RF commands.

14-58 Internal attitude control signal of the Tug shall be capable of being checked for accuracy by the Orbiter crew before release.

(OI) Tug internal attitude control signals will be available at the Aft Display and Orbiter maneuvers must be made to check accuracy of Tug subsystem before release

15-58 Tug propellant tank integrity shall be verified, pressures and hazardous fluid quantities shall be reduced to a safe value, and ordnance circuits shall be safed before Tug retrieval operations begin

(OI) The Tug main propellants will be dumped and system deactivated prior to Orbiter rendezvous operations as commanded by the Tug or by the ground or Orbiter as B/U Safety critical parameters will be supplied by RF to the Orbiter during rendezvous and retrieval operations

16-59 The Tug shall be visually inspected for docking readiness before retrieval

(OI) The Tug and Orbiter timeline and terminal interval attitude control system commands must provide for visual inspection for docking readiness before retrieval

Mechanical and Structural

17-60 A capability for remotely controlled expulsion of Tug main propellant tank residuals to space before retrieval operations and pressurization with the inert gases shall be provided

(OI) The dumping of Tug main propellant tank residuals can be controlled via the RF link (Orbiter or ground) as a backup-Tug onboard system is prime for this function

Propulsion

18-62 Interlocks shall be provided to assure that propulsion systems will not be fired while in the Orbiter payload bay and that no single operation shall result in propellants being dumped in the payload bay

(OI) Interlocks will be provided at the Orbiter interface to preclude propulsion system firing or propellant dumping in the payload bay

Avionics

19-63 Message signals for the Tug system, by hardwire and RF telemetry, shall be provided at the Shuttle Data Management System interface Measurements shall include Tug latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications This information should also be available prior to retrieval

(OI) Tug system caution and warning and system status measurements will be available to the crew prior to deployment via hardwire interfaces and prior to retrieval via RF telemetry

20-63 RF communication capability shall be available between the Orbiter and the Tug for command and control functions while separated from the Orbiter and up to a separation distance TBD

(OI) Orbiter/Tug communications link must be maintained for the separation distance stated

21-63 Tug critical command and control circuitry shall be designed to be fail operational/fail safe as a minimum

(OI) The first failure of Tug critical command and control circuitry will not result in any degradation of operational capability, it will be turned off by redundancy management The requirement (Fail Safe) shall not result in any hazardous function to occur is undefined and a concern listed in Section 2 2 1 2 requirement OTI-44-10-63

22-63 Tug autonomous navigation commands for attitude control and translation maneuvers shall be disabled until a safe separation distance and compatible trajectories can be verified

(OI) Tug autonomous navigation will be performed continuously throughout the mission The Tug attitude control system will be activated immediately upon Orbiter/Tug separation and deactivated at reattachment The Tug attitude maneuvers will be limited while the Orbiter is within TBD distance of the Tug The Tug main propulsion will be deactivated when the Tug is within TBD miles of the Orbiter

23-63 Commands affecting safety critical equipment status must have associated data transmission to provide a positive functional verification

(OI) Whenever an Orbiter command affects any Tug safety critical equipment, verification will be sent back to the Orbiter

24-64 The Tug electrical systems shall be designed with overload protection

(OI) Overload protection must be planned to isolate failures and protect other circuits

25-65 Positive indications of Tug electrical systems shut down status shall be provided to the Orbiter flight crew, prior to retrieval

(OI) The Tug requires the fuel cells until after retrieval The communications, telemetry and other Tug systems (DMS, IMU) require the fuel cells Status of the fuel cell will be sent to the Orbiter however

26-65 Tug shall have a means of shutting off its electrical power under emergency conditions

(OI) The electrical system design includes provisions for shutting off electrical power under emergency conditions

27-65 Fuel cells are to be activated only after TBD distance separation from the Orbiter

Tug fuel cells will be activated during prelaunch Stop or start of the electrical power system can be activated from the Orbiter Aft Station switch and via the RF link from either the ground or the Orbiter Live fuel cells, operating properly and monitored, are not considered a safety hazard

Spacecraft Safety Requirement

28-69 No single Spacecraft failure shall result in a hazard which jeopardizes the flight or ground crews, the general public, public/private property and the ecology (fail safe)

(OI) There will be no single point failure which can jeopardize people, property or ecology.

29-70 Spacecraft shall provide caution and warning data to the Orbiter and crew for safety critical functions while aboard or in the near vicinity of the Orbiter

(OI) Whenever the Spacecraft is within (aboard) or in close vicinity of the Orbiter, the status of safety critical Spacecraft functions will be available via the Tug TM or hardwired to the Orbiter

30-70 Safety critical single failure points shall utilize redundant control and measurement system

(OI) There will be at least dual control and monitoring of all Spacecraft safety critical single point failure points.

31-70 No single failure of the Spacecraft shall result in its unprogrammed motion while in the Orbiter or within TBD distance from the Orbiter

(OI) The Spacecraft will be interlocked, preventing any vehicle movement until the Spacecraft is a safe distance from the Orbiter

32-70 Provisions shall be made to confirm that all safety critical Spacecraft/Tug and Spacecraft/Orbiter interfaces are securely connected

(OI) All Spacecraft interfaces that could affect the safety of the Orbiter will have indicators showing they are securely connected while in the Orbiter bay and prior to retrieval by the Orbiter via C&W panel

General

33-70 Operations for rescuing an Orbiter crew shall not be hindered by a Spacecraft and/or its operation

(OI) Spacecraft will not interfere with any crew rescue attempts

34-70 Any Spacecraft subsystem operation which impacts safety during the launch and entry phases shall be monitored via C&W (caution and warning) and controlled from the Orbiter flight station

(OI) The Orbiter has direct control and monitoring capability over all Spacecraft functions that could impact Orbiter safety during launch and entry phases.

35-71 Provisions shall be made for verifying critical Spacecraft systems readiness before activation

(OI) Spacecraft safety critical systems will be verified ready before total Spacecraft activation by ground, Orbiter, or Tug

36-71 All electrical, mechanical and fluid connections between the Spacecraft and Tug and/or Orbiter shall be designed to be fail safe.

(OI) No single interface failure will cause an unsafe situation

Mechanical and Structural

37-72 A redundant relief capability shall be provided for Spacecraft tanks which automatically limits the maximum pressure Relief shall be through the Orbiter vent system overboard Over-pressure relief capacity shall be redundant to vent capacity (When vent capability is provided, relief capability need not be redundant)

(OI) Redundant means will be provided to insure that safe tank pressures are not exceeded

Propulsion

38-74 Spacecraft sequencing for attitude hold and main engine starting sequence shall be remotely code commanded to prevent inadvertent operations of the Spacecraft while in the Orbiter payload bay or during the deployment phase of operation

(OI) Inadvertant operation of the Spacecraft will be prevented by use of interlocks

39-74 Spacecraft APS shall be capable of being shut down by one command from ground and Orbiter control

(OI) Spacecraft APS will be capable of being inhibited from an external source

40-74 Provisions shall be made to verify completion of main engine propulsion system safing prior to retrieval

(OI) Propellant system passivation will take place prior to retrieval and will be verified by the ground

Avionics

41-75 Message signals from Spacecraft systems shall be provided at the Shuttle Data Management System interface Measurements shall include at least Spacecraft latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications

(OI) Spacecraft system caution and warning and critical subsystem measurements will be available to the crew prior to deployment via hardwire interfaces and prior to retrieval via Tug RF telemetry

42-75 RF communication capability shall be available between the Orbiter and the Spacecraft for safety related command and control functions while detached from the Orbiter and up to a separation distance of TBD

(OI) Orbiter/Tug communications link providing SC access will be maintained for the separation distance stated

43-75 Spacecraft critical command and control circuitry shall be designed to be fail-operational/fail safe as a minimum

(OI) The first failure of Spacecraft critical command and control circuitry will not result in any degradation of operational capability The requirement fail safe shall not result in any hazardous function to occur is undefined

44-75 Automatic event sequencing programs and automatic controls whose actuation could affect flight personnel safety shall be operative by the Orbiter, or by ground control enabling switches (command over-ride), e g , pyrotechnic sequences, automatic deployment sequences, etc

(OI) Automatically activated software safety critical functions will be initiated by either the Orbiter or ground only when the Orbiter is at a safe separation distance Automatic activation/deactivation (or command) of Tug APS at separation/retrieval is required

45-75 Commands affecting safety critical equipment status must have associated data transmissions to provide a positive functional verification

(OI) Whenever an Orbiter command affects any Tug or SC safety critical equipment, a verification will be sent back to the Orbiter

Electrical

46-77 Secondary power sources for safety critical functions shall be provided

(OI) Redundant power will be provided to safety critical functions

2 4 3 C&W Status Measurements and Annunciators Recommendation

The following is the flight operational recommendation for status measurements and C&W annunciators resulting from Tug safety requirements, subsystem and mission analysis

TUG SYSTEM STATUS TO C&W	ANNUNCIATORS
LH_2 Tank Pressure	Main Tank LH_2 Press
LO_2 Tank Pressure	Main Tank LO_2 Press
N_2H_4 Tank Temp 1	N_2H_4 Tank Temp
N_2H_4 Tank Temp 2	
N_2H_4 Tank Temp 3	
Fuel Cell LO_2 Pressure	Fuel Cell LO_2 Press
Fuel Cell LH_2 Pressure	Fuel Cell LH_2 Press
Depl Adapt Armed	Depl Adapt. Arm Safe
APS Armed	Tug APS Arm Safe
Tug Main Propl Armed	Tug Main Propl Arm Safe
Aux Battery Temp	Aux Battery
Spacecraft Depl Arm Safe	Spacecraft Arm Safe
H_E Bottle Press 1	H_E Bottle Press
H_E Bottle Press 2	
H_E Bottle Press 3	
Fuel Cell Temp 1	Fuel Cell Temp
Fuel Cell Temp 2	
+28 VDC Bus	Tug Critical Bus Voltage

NOTE This list of C&W functions is the result of coordinated efforts to date of both GDC (Interface Study) and IBM (Orbital Operations Study) but does not include Spacecraft requirements of 35 measurements (maximum) which are not identified by name

2 5 SPACE TUG SYSTEMS OPERATIONAL REQUIREMENTS ASSESSMENT

This is a summary of the Space Tug Systems Operational Interface Requirements as defined by the baseline documentation The following paragraphs contain the results of this assessment and incorporates actions resulting from data exchange meetings. The requirements are categorized into Implemented, Deleted, Exceptions and Proposed The category of "Implemented" contains the requirements upon which there is agreement and thus are being implemented In some cases, however, there is not a total operational definition available from companion studies With each requirement, is a statement elaborating on implementation. The category of "Deleted" consists of those requirements removed because of similarity, duplication and those not directly effecting the operational interface The "Exception" category consists of those requirements where there is not agreement and exception is being taken Rationale is given for the exception. The "Proposed" requirements category contains recommended requirements which became apparent during the assessment of existing requirements

2 5 1 Operational Requirements Implemented

The following requirements are those where there is agreement and, therefore, are being implemented as stated:

TS-1-17-139 Tug systems will be designed so that no on-board or ground command action will be nominally required during Orbiter ascent to orbit or descent and landing

Implementation - The Tug systems are planned so that commanding from the Orbiter or TOC is nominally not required during Orbiter ascent, descent or landing

TS-2-17-140 All mission critical functions shall have redundant measurements and redundant command capability

Implementation - All Tug mission critical functions are planned to have redundant measurements and command capability

TS-3-17-139 Prior to release, the Tug/SC checkout will be accomplished from the ground

Implementation - Tug and SC checkout will be done primarily by onboard systems as part of redundancy management of the Tug and by the SC's self checking capability. The ground, the TOC and the SCOC will be prime evaluator of detailed status however

TS-4-17-140 All mission critical systems shall be designed to fail operational and all others fail safe

Implementation - The Tug is planned to be as a minimum dual redundant for critical systems which means it will be operational after the first failure however, meeting the fail safe requirement is, undefined at this time and listed as a concern in Section 2.2 1 2 requirement OTI-44-10-63

TS-5-17-140 Insofar as possible, Tug shall be designed to permit recovery of the Tug/SC in the event of non-catastrophic malfunctions preventing a Tug burn.

Implementation - The Tug is planned to be recoverable if the main propulsion fails.

TS-6-17-140 Provide emergency jettisoning of Tug/SC deploying equipment and antennas to complete retrieval and storage operations of the Tug/SC

Implementation - There is no equipment on the Tug as planned that requires jettison for emergency retrieval The engine bell must be retracted but that can not be jettisoned.

TS-7-17-140 Tug shall be designed to minimize lead time and effort for mission preparation Specifically, mission-independent software shall be used insofar as possible, and software shall be designed for ease of mission-dependent changes

Implementation - Software is planned to be modular

TS-8-17-140 Systems management shall be automated where feasible with ground control backup

Implementation - The Tug is planned to be redundant and level II autonomous, therefore, it will contain onboard system management with ground control as a backup

TS-9-17-140 Telemetered measurements shall be provided for all parameters which must be maintained within critical limits or where a knowledge of these quantities is needed to determine the operational status or capability of a system.

Implementation - Tug critical system measurements are provided to the Orbiter when within 20 NM and all measurements are provided to the TOC as continuously as downlink coverage permits

TS-10-17-141 Propellant dump capability shall be available

Implementation - Propellant dump capability is available both while in the Orbiter and free flying

TS-11-17-141 Tug Support software necessary for maintenance and preparation of mission flight software shall be designed compatible with (TBD) NASA computers

Implementation - Must be stated TBD.

TS-12-17-141 All pressure vessels must have automatic relief capability.

Implementation - All Tug pressure vessels are planned to have automatic relief capability

TS-13-17-141 All venting of the Tug shall be non-propulsive.

Implementation - Tug venting is planned to be non-propulsive

TS-14-17-141 Tug shall have capability of isolating its electrical loads under emergency conditions. Ground override capability will be available.

Implementation - Isolation will be possible by redundancy management and ground override as a contingency is planned

TS-15-17-141 Sequence logic and pyrotechnic firing circuits shall be at least dual redundant, with ground control isolation capability

Implementation - All Tug logic is planned to be at least dual redundant.

TS-16-17-141 Safety design features such as interlocks, redundancy, grounding, and isolation devices shall be incorporated so that no premature detonation of explosive devices can occur. Ground control override capability shall be provided.

Implementation - No explosive devices are planned for Tug.

TS-17-17-141 The capability shall be provided for the modification or reload by the ground of the Tug software.

Implementation - TOC as planned can reload the Tug software.

TS-18-17-85 No operational Tug system should constrain a launch time of 24 hours after a launch scrub

Implementation - No Tug system as planned will constrain a launch time of 24 hours after a launch scrub

TS-19-17-88 The Tug on-board prelaunch targeting for planetary missions will be pre-loaded from the ground

Implementation - The Tug on-board prelaunch targeting for planetary missions are planned to be pre-loaded from the ground.

TS-20-17-95 The Tug on-board flight programs will be required to perform computations for four mission classes

(1) Geosynchronous

(2) Low Earth Orbit (near circular)

(3) Low Earth Orbit (elliptical)

(4) Planetary

Implementation - The Tug on-board flight programs are planned to perform computations for the four mission classes

TS-21-16-92 The Tug must have the capability for variable propellant loads.

Implementation - The Tug is planned to have the capability for variable propellant loads

TS-22-10-58 The planned attitudes of the Tug during release and separation from the Orbiter shall be such that the attitude control engines at no time accelerates the vehicle towards the Orbiter

Implementation - The mission planner will consider this, and Tug onboard GN&C will mechanize it

TS-23-10-58 Tug propellant tank integrity shall be verified, pressures and hazardous fluid quantities shall be reduced to a safe value, and ordnance circuits shall be safed before Tug retrieval operations begin

Implementation - The onboard program with command safing and commands will be backed up by the Orbiter and the ground.

TS-24-10-58 Provisions shall be made to pressurize propellant tanks of Tug to avoid implosion during return flight.

Implementation - The deployment adapter is planned to contain a H_E bottle for this purpose

TS-25-10-58 Tug attitude control or Tug main engine thrust shall not be used for initial separation of the Tug to a safe distance (TBD) from the Orbiter

Implementation - The Tug APS and MPS will not be fully enabled until TBD safe distance from the Orbiter

TS-27-10-58 Propellant tank pressures where practical shall not be increased to operational values until TBD distance from the Orbiter after deployment

Implementation - Propellant tank pressures will not be increased to operational values until the Tug is TBD distance from the Orbiter

TS-28-10-60 A capability for remotely controlled expulsion of Tug main propellant tank residuals to space before retrieval operations and pressurization with inert gases shall be provided

Implementation - The Tug will automatically safe main propellants, and the ground and Orbiter will backup the command if required

TS-29-10-15 The baseline Tug shall be compatible with the NASA STDN/TDRS and the AF SGLS/SCF communications and tracking systems

Implementation - The Tug is planned to be compatible with NASA STDN/TDRS and AF SGLS/SCF

TS-31-10-45 Alternate or redundant means of performing a critical function shall be physically separated or protected such than an event which causes the loss of one means of performing the function will not result in the loss of alternate of redundant means.

Implementation - Redundant means of performing critical functions are being physically separated as a goal

TS-32-10-16 Attitude update will be independent

Implementation - The Tug using star trackers, sun sensors and ILT is independent for attitude update

TS-33-10-16 Tug state determination will be independent, with secure ground augmentation command as optional (passive beacons are permissible)

Implementation - The Tug using an IMU and ILT is independent for state determination

TS-34-10-16 GN&C will be automatic & independent (includes preburn, burn, post burn targeting & reconfiguration) Use of ground-beacon acceptable

Implementation - GN&C will be automatic & independent and passive ground beacons will be used with ILT

TS-35-10-16 Shuttle rendezvous will be automatically accomplished by on-board computation of nav & guidance, except beacon optional for Shuttle contact All rendezvous are to be coplanar with Shuttle, including abort.

Implementation - Tug rendezvous with the Shuttle is planned to be automatic, with the Tug moving to a rendezvous box, then attitude holding until the Shuttle moves in and captures the Tug.

TS-36-10-16 SC docking will be accomplished automatically with target passive or not actively evasive Event telemetry will be with secure monitoring

Implementation - SC docking is planned to take place automatically after a visual inspection via TV The events will be telemetered with secure monitoring

TS-37-10-16 SC rendezvous will be automatically accomplished by terminal phase guidance with target passive Event telemetry will be with secure monitoring

Implementation - SC rendezvous is planned to take place automatically The events will be telemetered with secure monitoring

TS-38-10-19 The baseline Tug while in the payload bay shall provide systems status data to and receive commands from, Tug/SC Operations Center(s) via the Orbiter provided communications relay as defined in JSC 07700

Implementation - The Tug is planned to provide systems status data to and receive commands from TOC/SCOC via the Orbiter while onboard

TS-40-10-64 Safety critical control circuits shall be capable of being verified.

Implementation - Safe critical circuits are planned to be capable of verification

2 5 2 Operational Requirements Exceptions

The following is a requirement where there is not agreement and exception is taken Rationale is given for the exception

- Requirement from Baseline System Requirements and Guidelines, Vol 1, Paragraph 3 2 6 1 4 d (20)

TS-44-10-65 Fuel cells are to be activated only after TBD distance separation from the Orbiter

Rationale - Tug fuel cells will be activated during prelaunch Stop or start of the electrical power system can be activated from the Orbiter Aft Station switch and via the RF link from either the ground or the Orbiter Live fuel cells, operating properly and monitored, are not considered a safety hazard

2.5 3 Operational Requirements Deleted

The following 12 requirement numbers have been deleted from further consideration because most are operationally duplicates or have no impact on operational functions See Appendix A Section 4.0 for requirement statements and reasons for deletion.

DELETED REQUIREMENTS NUMBERS

TS-26-10-58	TS-42-10-65	TS-47-10-66
TS-30-10-46	TS-43-10-65	TS-48-10-66
TS-39-10-28	TS-45-10-75	TS-49-10-66
TS-41-10-65	TS-46-10-66	TS-50-10-66

2 5 4 Space Tug Systems Operational Requirements Proposed

The following requirements have been identified from the analysis of the Space Tug Systems operations and are proposed to be added to the baseline

1 Maintain LO_2 & LH_2 to run fuel cells for 4-5 hours following propellant dumps

The fuel cells are required to power the communication, telemetry, IMU and DMS until after Tug recovery by the Orbiter

2 Autonomous Navigation requires ILT or equivalent

Autonomous navigation is cost effective because it is independent of ground support costs ILT is proven to be the most accurate means of navigation update

3 Rendezvous & Docking Sensor Range (75-100 NM) minimum @ TPI

This requirements results in minimum expenditure of APS fuel

4 Fuel cells activated during prelaunch to supply tug power through ascent and on-orbit operations

The Tug power requirements exceed that available from the Orbiter and therefore require full Tug mission duration use of its fuel cells.

5 Telemetry from Tug to Orbiter and Tug to ground must be the same

This will allow one set of software to be used to encode and decode the telemetry for the various types of processing that will be required

6 Uplink (command) formats from ground thru Orbiter to Tug and from Ground to Tug must be the same

This will allow use of one set of software and or hardware encoders and decoders on the ground and onboard the Orbiter and the Tug

7 Orbiter to Tug RF must be established prior to umbilical disconnect

This is required to assure the safety of the Orbiter and it's ability to control the Tug once it is free flying

8 Design Goal - IUS and Tug, telemetry and command formats should be the same or similar

This is required to allow ease of transition i e. personnel training, reuse of some procedures, reuse of software and or hardware encoders and decoders on the ground and onboard the Orbiter, the IUS and the Tug

9 360^{o} Antenna Radiation for both telemetry and command

This is required for safety to allow minimum attitude constraint between Tug and the Orbiter (whose violation will result in communication drop outs) while the Tug is operating close to, and is a hazard to, the Orbiter

10 On-orbit target update capability is required

As part of contingency planning, to accommodate a variety of partly failed hardware situations, it will be necessary to do a target update on-orbit

SPACE TUG MISSION OPERATIONS ANALYSIS 3

The Space Tug missions consist of delivery to and/or retrieval of Spacecraft from orbits outside the performance range of the Shuttle Orbiter Missions are currently planned in the following Spacecraft disciplines Astronomy; High Energy and Solar Physics, Atmospheric Physics, Earth Observation, Communication and Navigation, and Planetary Mission sources include NASA, DoD, commercial and foreign users.

This section presents typical sets of Space Tug missions which were analyzed to determine operational requirements

Three typical mission models were utilized during the study for the years 1984-1991 These models contained representative payload (SC) classes, flight frequency, and estimated payload weights and dimensions They were grouped according to their destination (1) Sun Synchronous, (2) Geosynchronous, and (3) Interplanetary The three mission models used in this study were, (1) Space Shuttle Traffic Model, October 1973, (2) the DoD Traffic Model and (3) a summary traffic model developed by the NASA Tug task team during the course of the study Figure 3 0 0-1 shows the mission type, anticipated launch schedule, maintenance time and mission planning, training and simulation intervals for 1984 The year 1984 launch density was extracted from the mission model to determine overlaps in missions As can be seen, there is no overlap of Space Tug missions, therefore, sizing estimates for the study are based on single mission requirements. It should be kept in mind that these data are only representative of what should be expected In particular, planning and operational analyses should investigate the impact of variations in the relative frequency of the various classes, changes in the Spacecraft characteristics, and other factors that may change and are a part of operational planning

3 1 REFERENCE MISSION DESCRIPTIONS

The following paragraphs describe the types of reference missions evaluated during the study To enable the identification of operational requirements from the many diverse missions, the individual missions were grouped into three major classes and analysis performed on each class The three classes used were, (1) Geosynchronous Missions, (2) Sun Synchronous Missions, and (3) Interplanetary Missions Characteristics of these mission classes are discussed in the following paragraphs

3 1 1 Geosynchronous Missions

Several types of Geosynchronous Missions are defined in the current traffic models These missions can be grouped into, (1) deploy only, (2) retrieval only, (3) deploy one Spacecraft and retrieve one Spacecraft, and (4) deploy two Spacecrafts and retrieve one Spacecraft The mission sequence for the deployment of two Spacecrafts and retrieval of one is presented in Table 3 1 1-1 In this case, it was assumed that the Spacecrafts were located 60^{o} apart (longitude)

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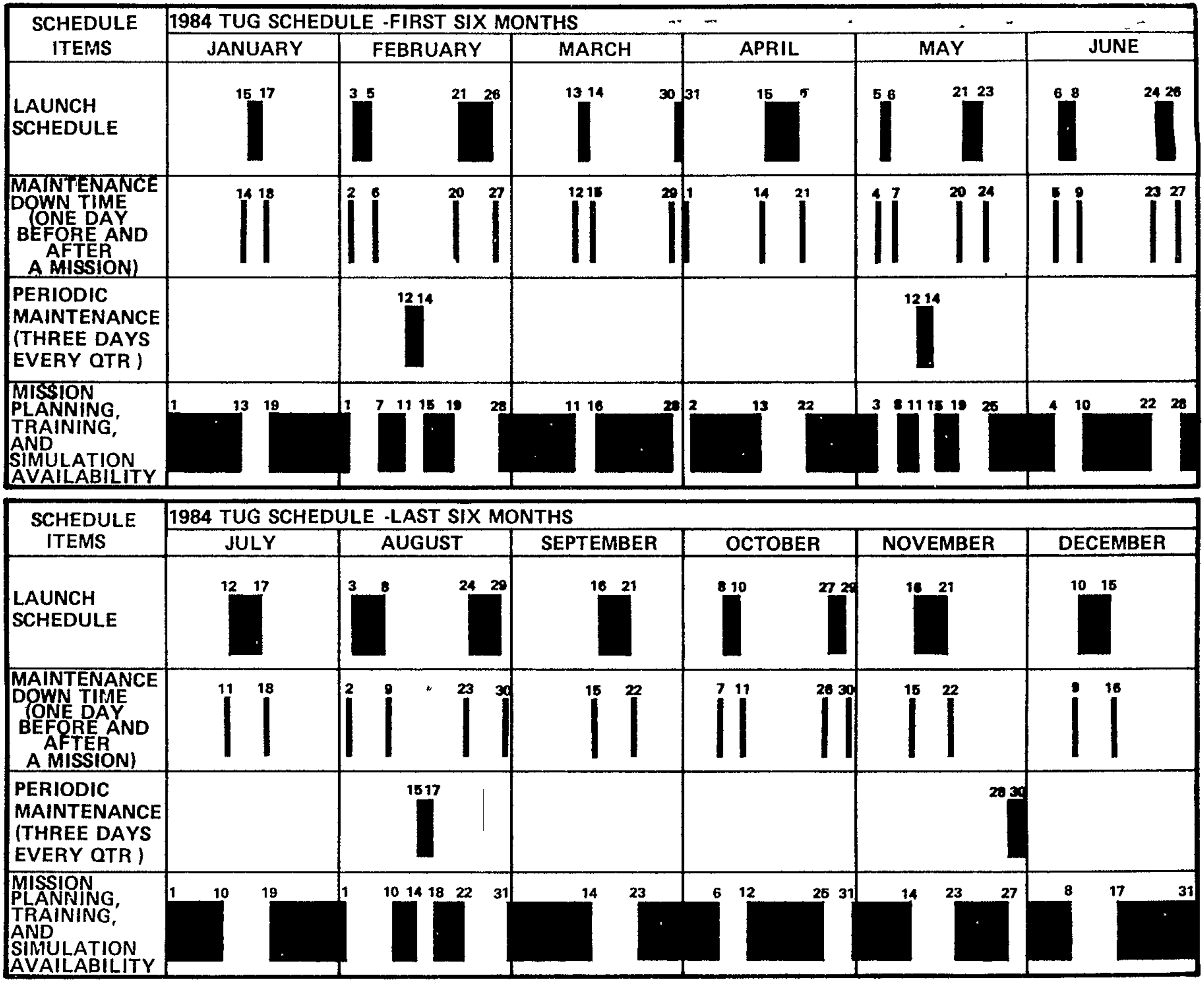


Figure 3 0 0-1 1984 Space Tug Launch Schedule

Table 3 1 1-1 Mission Sequence for a Dual Deployment, Single Retrieval Geosynchronous Mission

	EVENT	INITIAL WT (lbs)	APS (lbs)	INERTS LOSSES	EVENT DURATION (Hrs)	TOTAL TIME (Hrs)	Δ V (F/S)
1	Tug Separation from Orbiter	58 855	8 6	10 0	2 0	2 0	
2	Phase in Shuttle Orbit	58 836	21 4	46 0	11 0	13 0	
3	Burn into Phasing Orbit (Full thrust)	58 769	-	-	0 13	13 13	4494
4	Coast in Phasing Orbit, One Revolution	43,271	17 5	5 0	3 0	16 13	
5	Inject into Geosynchronous Transfer (Tank head idle + full thrust)	43 248	-	-	11	16 24	3672
6	Coast to Midcourse Correction	33 678	13 8	6 0	1 5	17 74	
7	Midcourse Correction (Tank head idle + pump idle)	33,658	-	-	03	17 77	50
8	Coast to Geosynchronous	33 536	14 0	16 0	3 96	21 73	
9	Circularize at Geosynchronous (Tank head idle + full thrust)	33,506			12	21 85	5826
10	Coast and Orbit Trim	22 529	102 7	56	12 0	33 85	
11	Deploy First SC (1,000 lbs)	22,370	31 5	-	1 0	34 85	
12	Inject into Phasing Orbit (Tank head idle + pump idle)	21 338	-	-	05	34 90	480
13	Coast in Phasing Orbit	20 623	13 7	105	28 0	62 90	
14	Circularize at Geosynchronous (Tank head idle + pump idle)	20 504	-	-	05	62 95	480
15	Deploy Second SC (1,000 lbs)	19,816	37 7	6	1 0	63 95	
16	Inject into Phasing Orbit (Tank head idle + pump idle)	18,772	-	-	04	63 99	258
17	Coast 1 5 Revolutions in Phasing Orbit	18,426	14 7	146	39 0	102 99	

Table 3.1.1-1 Mission Sequence for a Dual Deployment, Single Retrieval Geosynchronous Mission (Continued)

	EVENT	INITIAL WT (lbs)	APS (lbs)	INERTS LOSSES	EVENT DURATION (hrs)	TOTAL TIME (hrs)	Δ V (F/S)
18	Height Adjustment Burn (Tank head idle)	18,266	-	-	01	103 00	10
19	Coast in Adjusted Phasing Orbit	18,251	11 1	49	13 0	116 00	
20	Phasing Orbit Circularization (Tank head idle + pump idle)	18,191	-	-	04	116 04	258
21	SC Rendezvous and Retrieval (1200 lbs)	17,856	96.5	15	4 0	120 04	
22	Phase at Geosynchronous for Nodal Crossing	18,944	11 2	45	12 0	132 04	
23	DeboostBurn (Tank head idle + full thrust)	18,888	-	-	.08	132 12	5840
24	Coast to Midcourse Correction	12,686	7.5	6	1 0	133 12	
25	Midcourse Correction (Tank head idle)	12,673	-	-	01	133.13	13
26	Coast to 170 n mi. Perigee	12,659	8.1	24	4.2	137 33	
27	Inject into Return Phasing (Tank head idle + full thrust)	12,627			05	137 38	3791
28	Coast 1 Revolution in Phasing	9,751	7.8	18	3.0	140 38	
29	Circularize at 170 n mi (Tank head idle + full thrust)	9,725			05	140 43	4243
30	Rendezvous with Shuttle (SC - 1200 lbs propellant reserve - 276 lbs)	7,280	32.4		4.0	144 43	

As the evaluation of geosynchronous missions (Figure 3 1 1-1) progressed, it was determined that missions could be represented by a standard set of building blocks where each block (or module) contained those operational functions (or tasks) required for mission completion Once these buildings blocks were

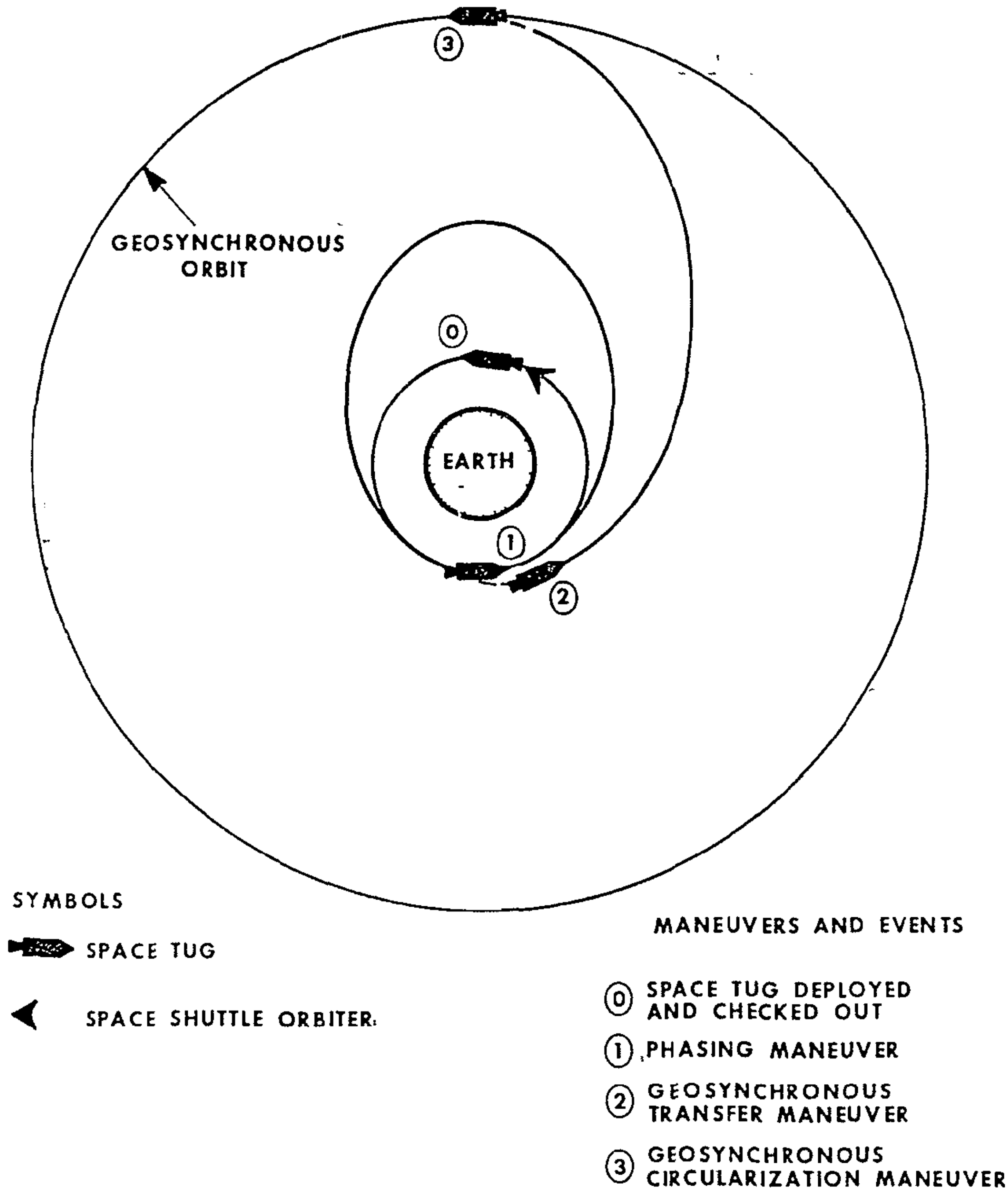


Figure 3 1 1-1 Space Tug Geosynchronous Ascent Profile

defined, they could be interleaved to represent specific missions. Paragraph 3 2 describes this modular approach and contains the functions within each standard module

As an example, Figure 3 1.1-2 depicts the standard modules designed to represent a single placement, single retrieval geosynchronous mission.

3 1 2 Sun Synchronous Missions

The Sun Synchronous mission class assumes a Space Tug deployment in low-earth orbit (≈205 NM) by the Orbiter and a transfer below and behind a Spacecraft in a 900 NM circular orbit. After orbital trims and the terminal rendezvous sequence has been completed, the Tug deploys a Spacecraft and retrieves another. The Tug then executes the two burn maneuver to place the Tug in a 215 NM orbit ahead of the Orbiter The geometry for this mission class is defined by Figure 3 1 2-1

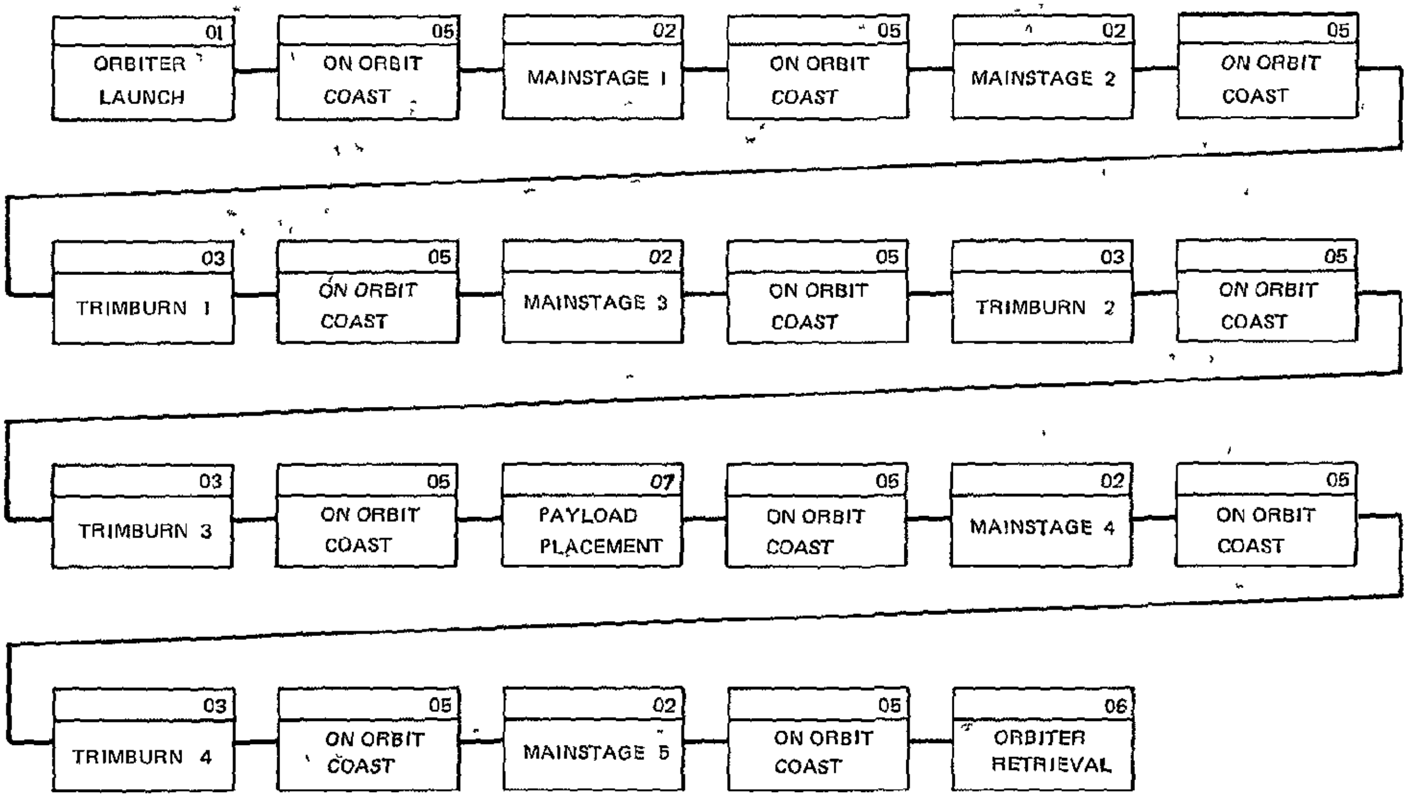
As in the Geosynchronous Mission class, the standard operational modules were interleaved to represent the Sun Synchronous missions. Figure 3 1 2-2 depicts a Sun Synchronous mission for a single placement, single retrieval case

3 1 3 Interplanetary Missions

There is little doubt that the Space Tug can satisfy the requirements of most of the Geosynchronous and Sun Synchronous missions. However, planetary missions are unique in that the delta-velocity requirements are high and this mission class has not received the depth of analysis of other classes.

The flight profile selected for the Space Tug planetary mission class is illustrated by Figure 3 1 3-1 The first maneuver required of the Tug after deployment and checkout is an elliptical transfer maneuver which is designed to break the Tug partial escape maneuver into two maneuvers to reduce the gravity losses The second Tug maneuver places the vehicle on a partial escape conic. The Spacecraft then separates and the kick stage (if required) supplies the additional delta-velocity needed to place the SC on the desired escape conic The third Tug maneuver occurs after sufficient time has elapsed after maneuver two to permit a turn-around into a retro firing position and places the Tug on an elliptical trajectory with the perigee radius in the vicinity of the desired Tug return orbit Maneuvers three, four and five will require plane changes to compensate for the nodal regression rate differences between the Orbiter and the Tug The fourth Tug maneuver places the Tug into an elliptical phasing orbit and maneuver five is designed to circularize the Tug into an orbit above, ahead, in-phase and in-plane with the Orbiter Maneuver four is added to give the Tug the additional flexibility to compensate for navigation errors and maneuver execution errors that would potentially place the Tug outside of the Orbiter retrieval box capability

The targeting requirements for using the Space Tug in a planetary mission are complex and will require a sophisticated prelaunch targeting program to optimize the Tug propellant loading when given a Spacecraft description and turn around time constraints for the Tug return phase. The complexity of this mission makes it desirable to baseline a day-to-day launch on time (no daily launch window). Prelaunch targeting shall determine the launch time and Orbiter orbital insertion targeting parameters (taken from the Space Shuttle data bank) necessary for



MISSION MODULE SEQUENCE FOR GEOSYNCHRONOUS SPACECRAFT DELIVERY TUG MISSION (SINGLE PAYLOAD PLACEMENT)

Figure 3 1 1-2 Mission Module Sequence for Geosynchronous Spacecraft Delivery Tug Mission (Single Payload Placement)

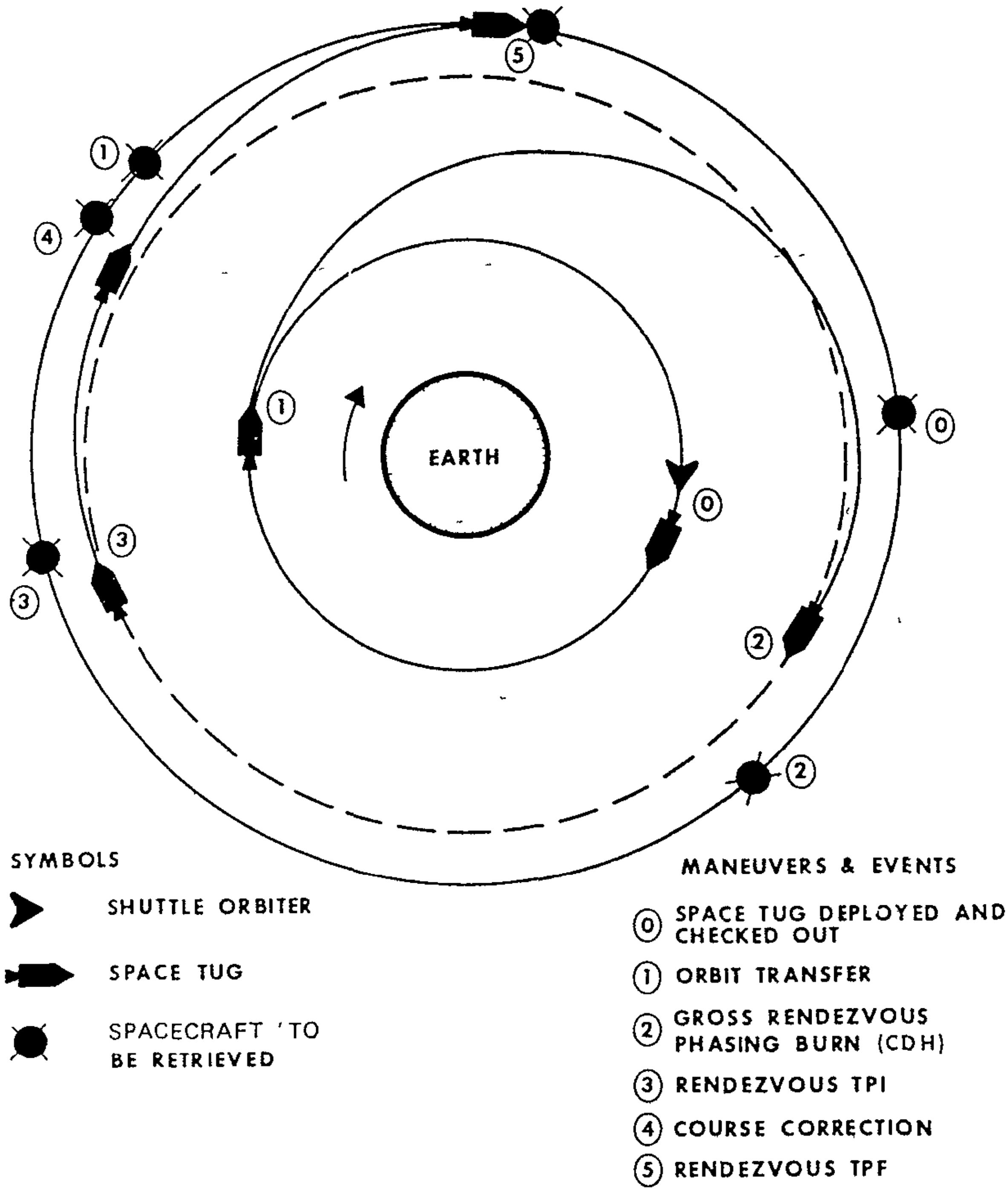
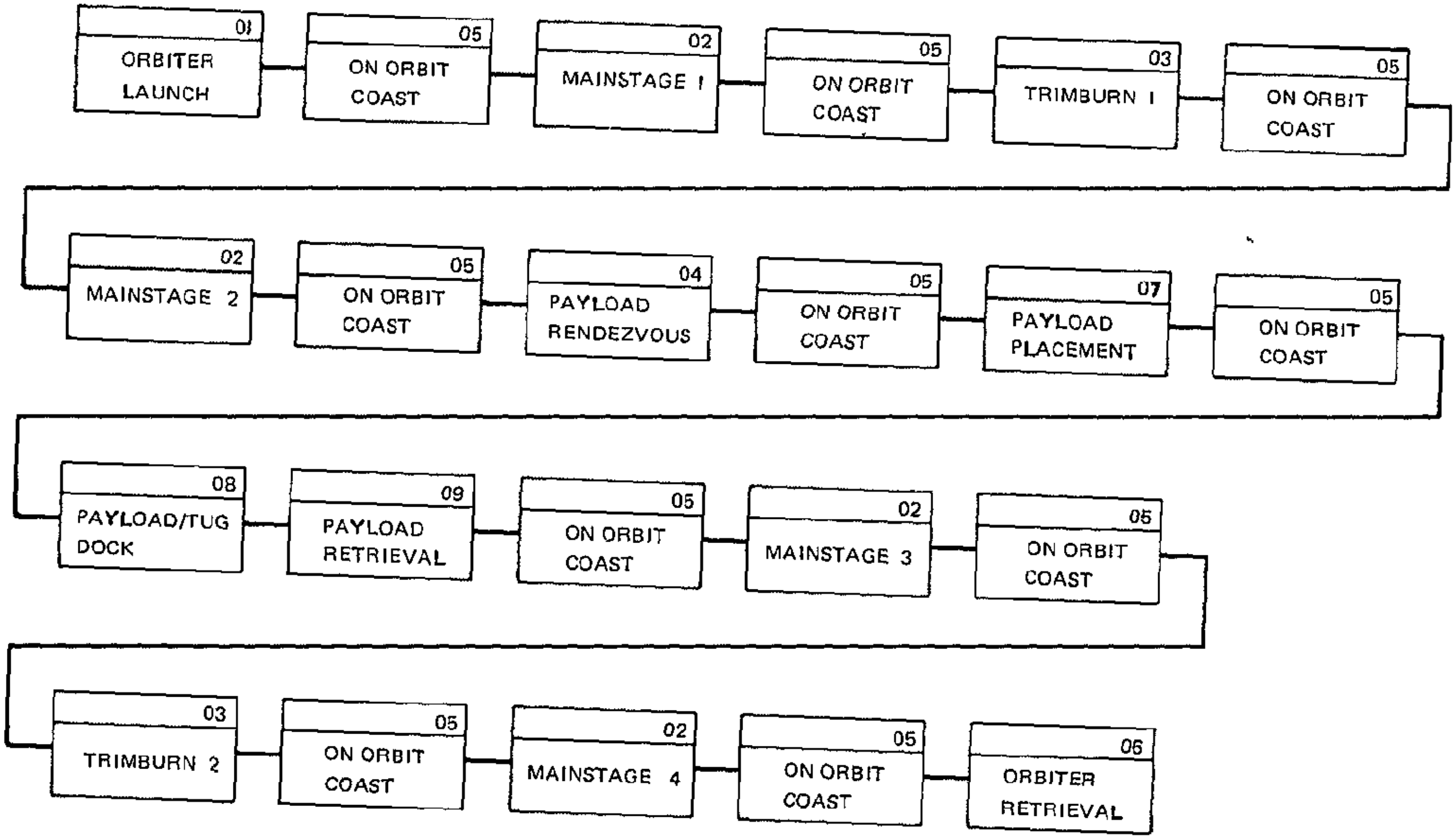


Figure 3 1 2-1. Space Tug Near Circular Rendezvous Maneuver Sequence



MISSION MODULE SEQUENCE FOR SUN SYNCHRONOUS MISSION (SINGLE PAYLOAD PLACEMENT/SINGLE PAYLOAD RETRIEVAL)

Figure 3 1.2-2 Mission Module Sequence for Sun Synchronous Mission (Single Payload Placement/Retrieval)

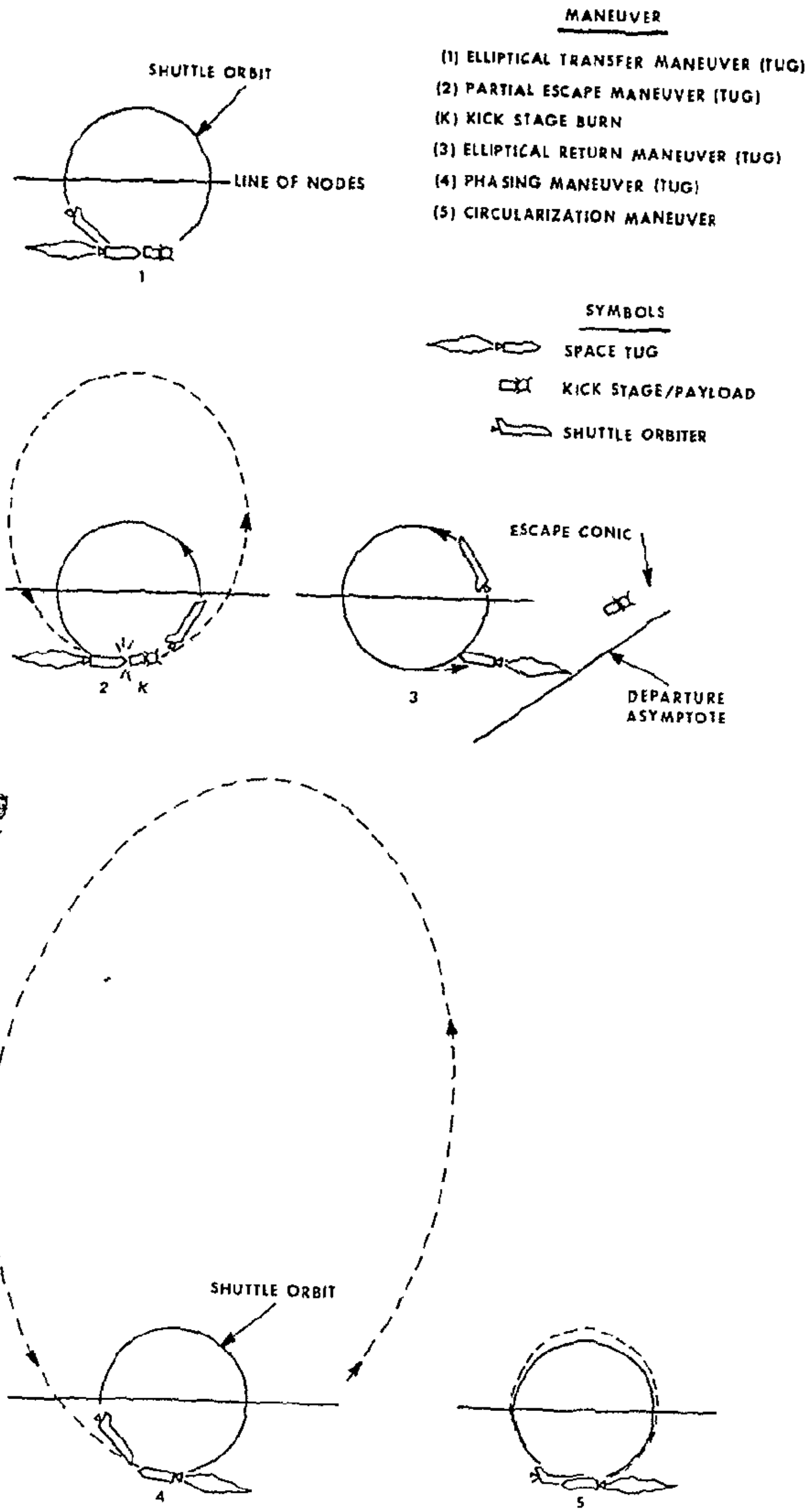


Figure 3 1 3-1 Space Tug Planetary Transfer/Return Profile

Space Tug deployment, the on-orbit targeting parameters for Tug maneuvers one through five, and the phase adjustment targeting parameters to compensate for off-nominal Orbiter/Tug phasing conditions at ignition of maneuver four The guidance presettings can be derived from the targeting parameters The Tug on-board targeting for planetary missions is baselined to be pre-loaded from the ground The mission shall require a dedicated Orbiter in the sense that no unplanned maneuvers (prior to launch) shall be made which will destroy the original Orbiter ephemeris after Tug/kick-stage/SC deployment

As in the other mission classes, standard operational modules were interleaved to represent the interplanetary mission Figure 3 1 3-2 depicts an interplanetary Space Tug mission for a single placement case

3 2 MISSION MODULE TIMELINES

Prior Space Tug studies have revealed that mission event sequences (timelines) can be modularized (subdivided into the longest consecutive sequence of events which occur in the same order for a particular function) The modularization of mission event sequences is a common technique used in most airborne flight programs to segregate similar computer functions This technique simplifies maintenance of the program by limiting the effect of changes to smaller areas of consideration and facilitates the calling of functions when a particular action is required

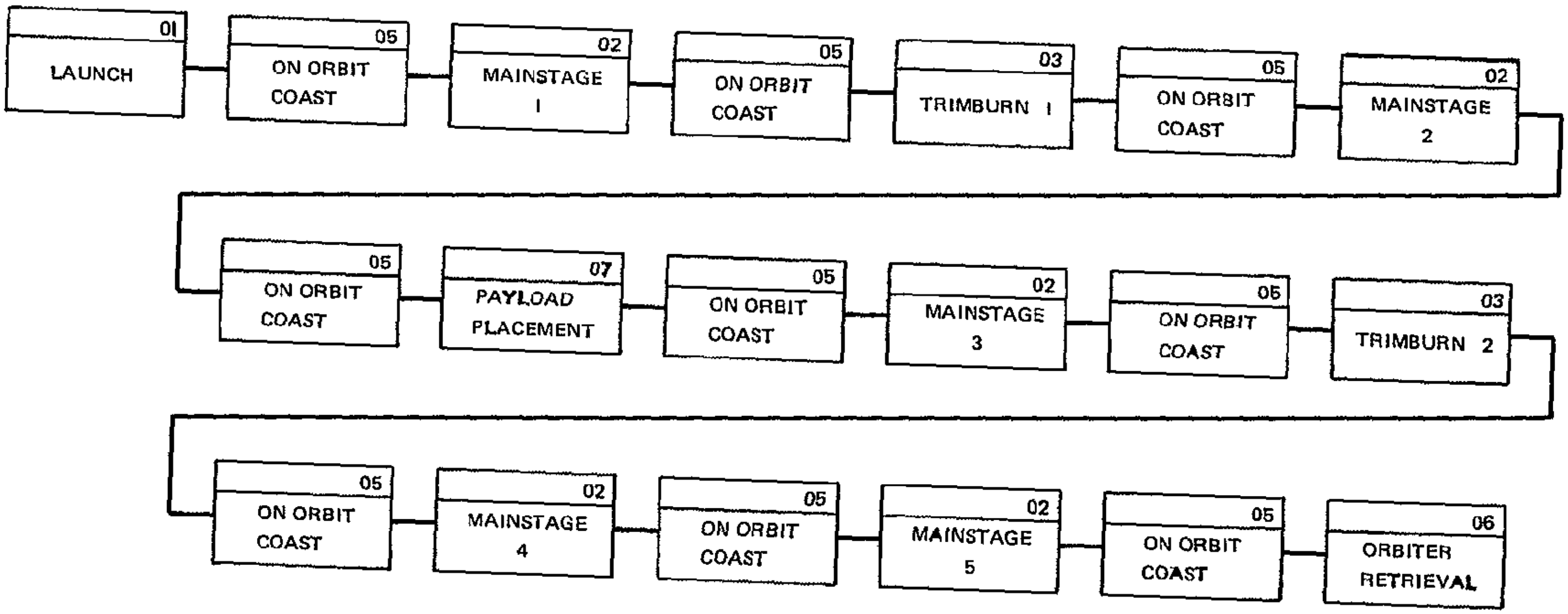
3 2 1 Principles of Mission Modularization

The development of the NASA Space Tug mission modules (timelines) evolved from work from prior Tug studies, concurrent analysis, and past experience The first step in the process was to identify the major functions common to any possible Tug mission The major functions for Tug mission were found to be Orbiter launch operations, on orbit coast, Tug mainstage burn, Tug trimburn, payload placement, payload rendezvous, payload docking, payload retrieval, payload service, Orbiter retrieval, and abort

With these major functions it is possible to construct a sequence of operations which satisfy the total mission spectrum These functions also accommodate the unplanned situations which the Tug is expected to handle Deviations to the nominal mission sequence will result in entry to one of these modules

After the identification of the major mission functions, the sub-functional sequence within each module was established Flow charts are included with each mission module timeline to visually depict the major functions within each module The Orbiter, Crew, Tug, and Tug Operations Center (TOC) activities associated with each sub-function were constructed, sequenced, and timed These activities are the events listed in each timeline

The identification of each event has been accomplished by assigning a two digit number to represent the event position in the module sub-function sequence This is the number immediately to the right in the identification number column of the time line tables The next two digits represent the general sequence of sub-functions within the module Some sub-functions, like some events, are not necessarily sequential The third double set of digits are the module identification number It is possible to extend the modules into a next



MISSION MODULE SEQUENCE FOR INTERPLANETARY TUG MISSION (SINGLE PAYLOAD PLACEMENT)

Figure 3 1 3-2 Mission Module Sequence for Interplanetary Tug Mission (Single Payload Placement)

numbering level which would then be module groupings for a particular mission The positive identification of events also permits the tracing and quantifying of events for analytical purposes

Duration times for sub-functions and associated events appear both in hours and minutes These times are tabulated in columns opposite the identification number followed by a mission reference time which is related to a key event within the module Key events are those events which commit the mission to a new phase Bar charts to the extreme right have been created to provide a picture of event time duration and sequence relative to the-total module activity Times for many events represent best estimates and are subject to change as refinements in mission definition, vehicle and ground systems continue

3 2 2 Mission Modules

The mission modules addressed in this section are

1 Orbiter Launch Operations

2 On Orbit Coast

3 Mainstage

4 Trimburn

5 Payload Placement

6 Rendezvous

7 Docking

8 Payload Retrieval

9 Service

10 Orbiter Retrieval

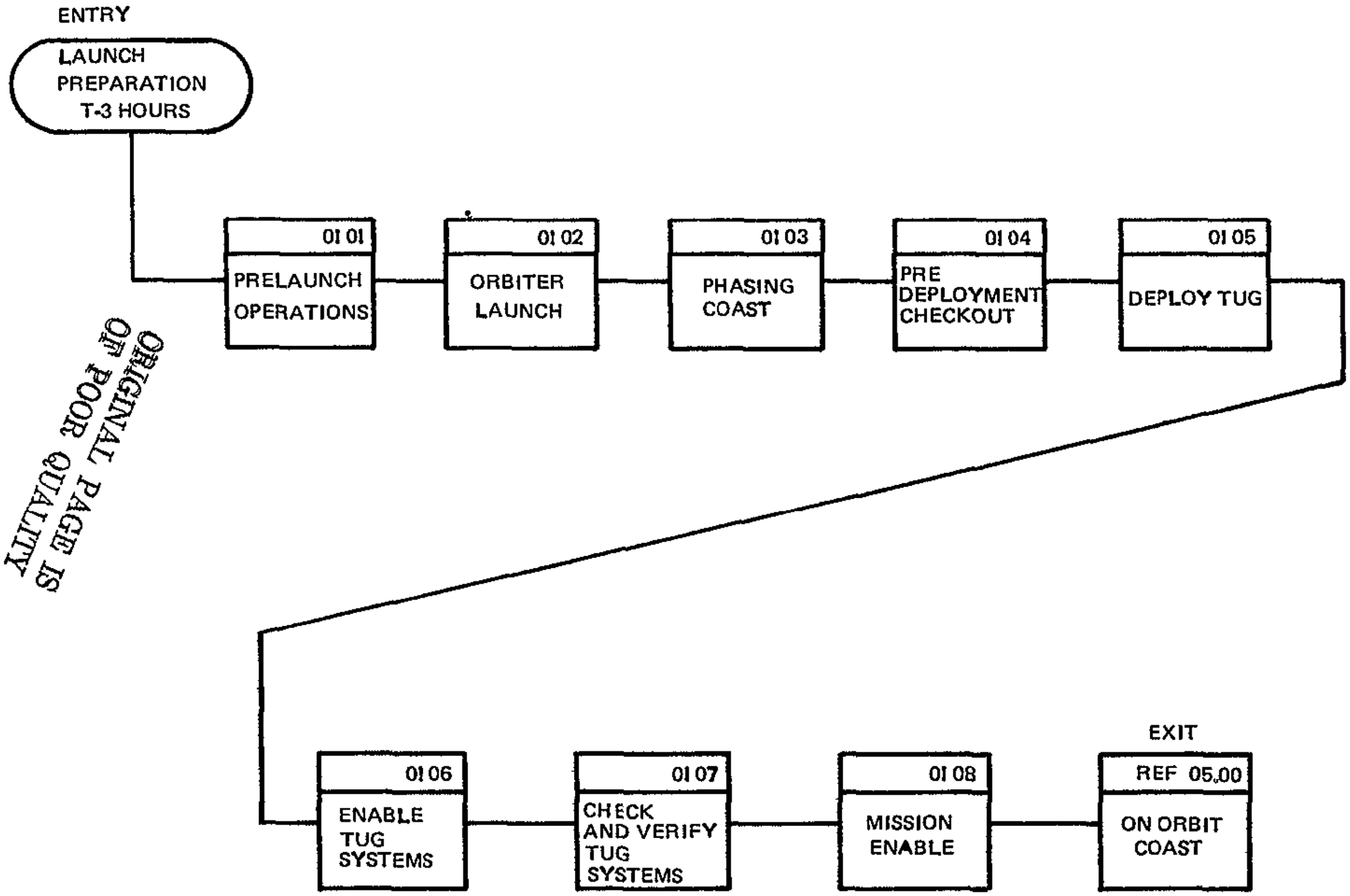
11 Abort

3 2 2 1 Orbiter Launch Operations

The Orbiter Launch Operations function is composed of a sub-set of eight sequential sub-functions which are entered from the launch preparation phase T-3 hours and terminated with the Tug in low earth orbit, checked out, and waiting convergence of its targeting equations for first engine burn Figure 3 2 2-1 is a flow diagram illustrating the sub-functional sequence within the module Table 3 2 2-1 is the major Tug, Orbiter, and TOC events occurring during a nominal Orbiter Launch Operations module

3 2 2 1 1 Prelaunch Operations

During the prelaunch operations from T-3 hours till liftoff the final preparations for boost to orbit will be made The Orbiter crew will ingress and begin monitoring Tug Caution and Warning parameters They will also support prelaunch



STANDARD ORBITER LAUNCH OPERATIONS MODULE

Figure 3.2.2-1 Standard Orbiter Launch Operations Module

Table 3.2.2-1 Standard Orbiter Launch Operations Module

STANDARD ORBITER LAUNCH OPERATIONS MODULE (01)

The Orbiter launch operations module begins in the prelaunch phase during the final integrated test during which there is Tug operations control center involvement and terminates with the Space Tug in the Space Shuttle orbit completely checked out awaiting convergence of its targeting equations for its first main engine burn

ENTR: Tug and Payload in Orbiter Bay or Pad at T-3 Hours

EXIT On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
PRELAUNCH OPERATIONS	01 00	03 000	-11 767	
MONITOR CAUTION & WARNING	01 01	03 000	-11 767	
VERIFY TUG SYSTEMS GO	01 02	00 417	-09 851	
SIMULATED FLIGHT MONITOR	01 03	00 333	-09 434	
COMMAND SYSTEM CHECKOUT	01 04	00 167	-09 101	
TELEMETRY SYSTEMS CHECKOUT	01 05	00 167	-08 934	
TARGET UPDATE LOAD	01 06	00 083	-08 867	
TUG FUEL CELL ELECTRICAL POWER ON	01 07	00 017	-08 784	
ORBITER LAUNCH (LIFTOFF)	02 00	00 217	-08 767	
VENT PROPELLANTS	02 01	00 167	-08 767	
ASCENT MONITOR CAUTION & WARNING	02 02	00 167	-08 767	
CIRCULARIZE MONITOR CAUTION & WARNING	02 03	00 050	-08 600	
PHASING COAST	03 00	08 000	-08 550	
PHASE TO TUG MISSION REQUIREMENTS	03 01	08 000	-08 550	
MONITOR TUG SYSTEMS	03 02	08 000	-08 550	
MONITOR CAUTION & WARNING	03 03	08 000	-08 550	
VENT PROPELLANTS	03 04	08 000	-08 550	
PRE-DEPLOYMENT CHECKOUT	04 00	00 267	- 0 550	
ACTIVATE/CHECK NON-PROPUL SYSTEM	04 01	00 250	0 550	
IMU INITIALIZATION	04 02	00 050	0 500	
CHECK NAVIGATION AGAINST ORBITER	04 03	00 083	0 450	
ORIENT TO DEPLOYMENT ATTITUDE	04 04	00 017	0 367	
VERIFY PAYLOAD SYSTEMS GO	04 05	00 083	0 367	
ATTITUDE REFERENCE UPDATE	04 06	00 017	0 350	
NAVIGATION UPDATE	04 07	00 017	0 333	
PAYLOAD BAY DOORS OPEN	04 08	00 033	- 0 317	
TUG SYSTEMS CONFIGURED FOR DEPLOY	04 09	00 033	- 0 317	

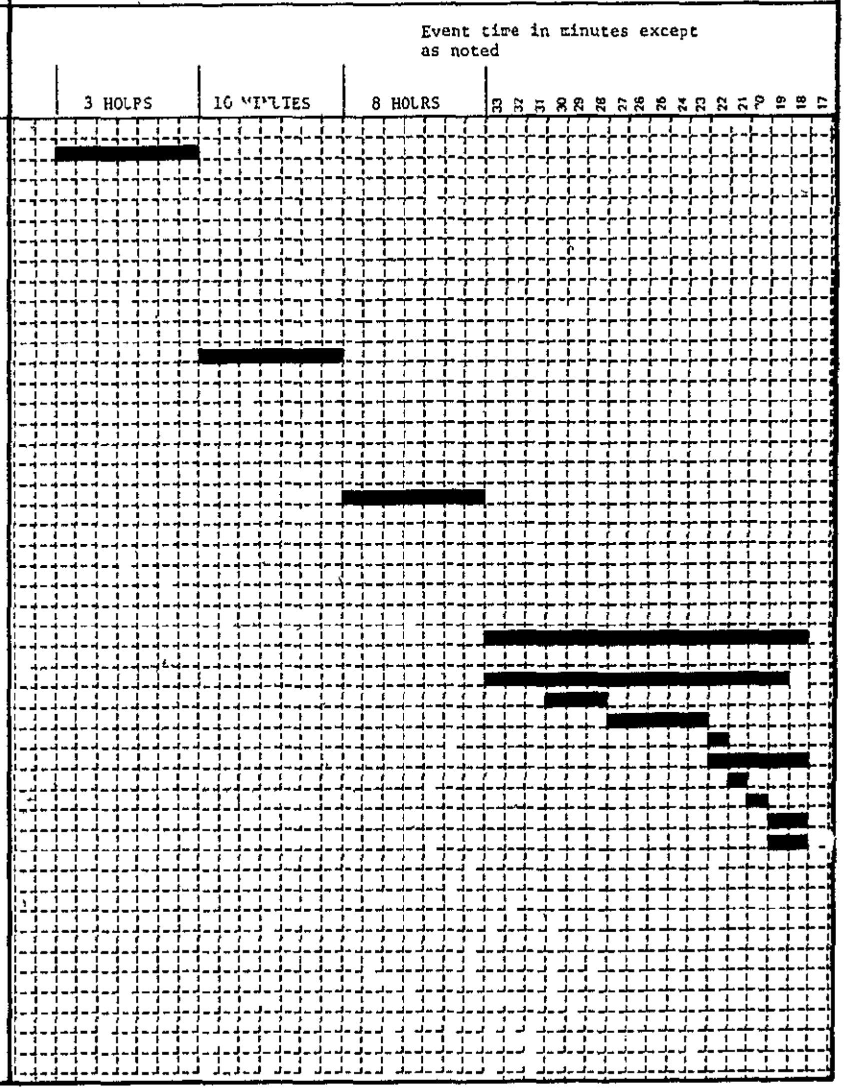
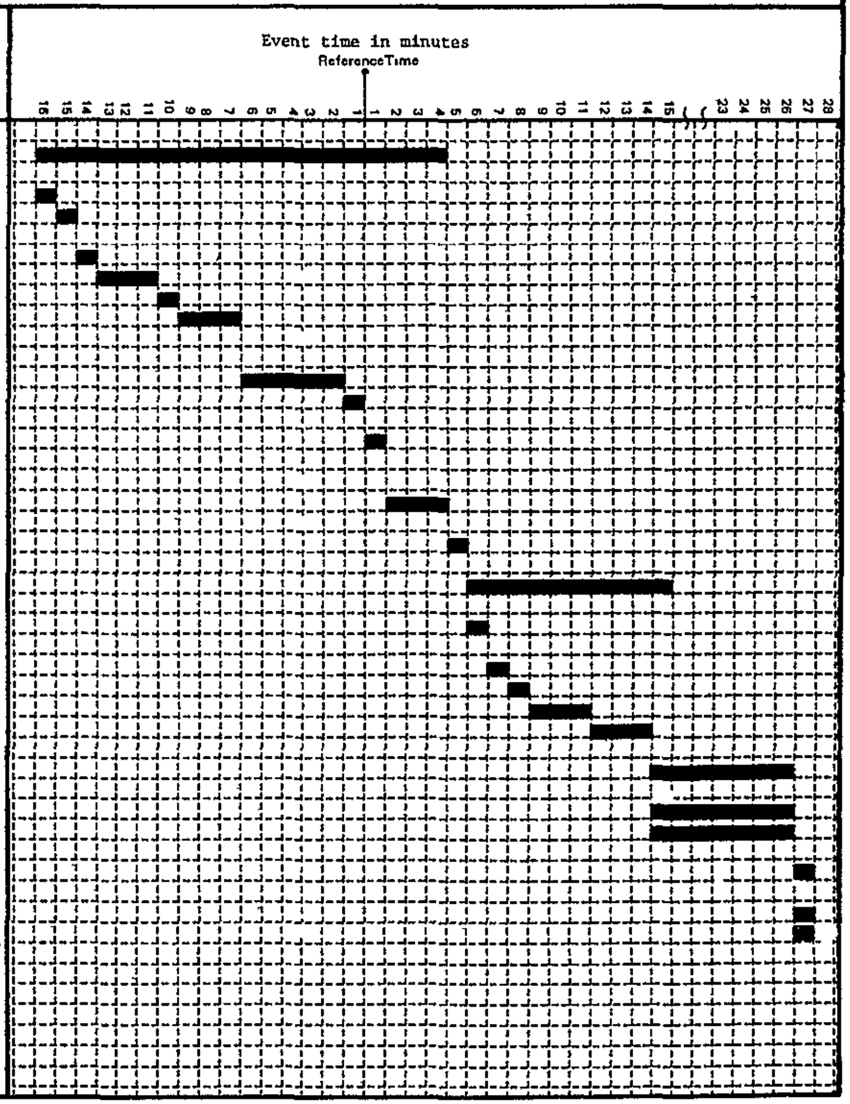


Table 3 2 2-1 Standard Orbiter Launch Operations Module (Continued)

STANDARD ORBITER LAUNCH OPERATIONS MODULE (01) (CONTINUED)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
DEPLOY TUG	05 00	00 333	- 0 267	
ELECTRICAL POWER TRANSFER	05 01	00 017	- 0 267	
FLUID AND PAYLOAD UMBILICALS RETRACTION	05 02	00 017	- 0 250	
FORWARD LATCHES RELEASED	05 03	00 017	- 0 233	
ROTATION TO REMOVAL POSITION	05 04	00 050	- 0 217	
RMS/TUG ATTACHMENT	05 05	00 017	- 0 167	
TUG/ORBITER RF TM/CMD LINK ESTABLISHED AND VERIFIED	05 06	00 050	- 0 150	
TUG/DA SEPARATION	05 07	00 000		
TUG REMOVAL BY RMS	05 08	00 083	- 0 100	
APS ARM (HARDWARE ENABLED, SOFTWARE INHIBITED)	05 09	00 017	- 0 017	
RMS/TUG SEPARATION	05 10	00 017	REF	
TUG APS ACTIVE (ATTITUDE HOLD)	05 11			
ORBITER EVASIVE MANEUVER	05 12			
TUG/GROUND RF TM/CMD LINK ESTABLISHED AND VERIFIED	05 13	00 050	0 067	
TUG CONTROL HANDOVER TO GROUND	05 14	00 017	0 083	
ENABLE TUG SYSTEMS	06 00	00 167	0 100	
ISSUE ENABLE/ACTIVATION SEQUENCE COMMAND	06 01	00 017	0 100	
ACCEPT ENABLE SEQUENCE COMMAND	06 02	00 017	0 117	
INITIATE ATTITUDE MANEUVER CAPABILITY	06 03	00 017	0 133	
EXTEND MAIN ENGINE NOZZLE	06 04	00 050	0 150	
ACTIVATE MAIN PROPULSION SYSTEM	06 05	00 050	0 200	
CHECK AND VERIFY TUG SYSTEMS	07 00	0 200	0 250	
CONDUCT FULL SCALE CHECKOUT	07 01	00 200	0 250	
MONITOR SYSTEMS PERFORMANCE	07 02	00 200	0 250	
MISSION ENABLE	08 00	00 017	0 450	
COMMAND MISSION ENABLE	08 01	00 017	0 450	
MONITOR SEQUENCE	08 02	00 017	0 450	



Tug checkout where required. The Tug vehicle will be cycled through final preflight checks including simulated flight, command, and telemetry checks Target update will be permitted late in the countdown if required. The Tug electrical power will be transferred to the Tug fuel cell power system prior to liftoff to assist the Orbiter with the extensive boost to orbit power requirements

3 2 2 1 2 Orbiter Launch (Liftoff)

During the boost to orbit by the Orbiter, both the Orbiter crew and the Tug Ground Control Center monitor the safety critical Tug Caution and Warning parameters The nominal function of the Tug during this time period will be to supply its own electrical power and maintain a safe state Maintaining a safe state will include the venting of propellants to maintain proper tank pressures

3 2 2 1 3 Phasing Coast

During phasing coast and circularizations maneuvers, the Tug will be maintained in the same state as boost However, it is possible and likely that Tug pre-deployment actvities will commence duing this period

3 2 2 1 4 Pre-deployment Checkout

The pre-deployment checkout of the Tug will be initiated approximately 16 minutes prior to the start of the actual deployment sequence. During this time the Orbiter will be maneuvered to the appropriate deployment attitude and the payload bay doors will be opened The Orbiter systems necessary for deployment will be activated and readied for the deployment operation

During this period, the Tug IMU will be initialized and Tug/Orbiter navigation compared If an attitude and/or navigation update is required at this time it can be issued to the Tug via the Orbiter Ground control personnel will evaluate Tug data telemetered via Orbiter telemetry and ascertain if Tug functions are nominal and the Tug is ready for deployment The Orbiter crew and Tug Operations Center will concur that the Tug is ready for deployment

3 2 2 1 5 Deploy Tug

The scheduled time allowed for the deployment sequence is twenty minutes This time is representative of current procedure and hardware requirements and can vary with refinements and changes

The deployment sequence is initiated with the Tug vehicle on internal power and configured for deployment The Orbiter crew begins the process by disconnecting and retracting the fluid and payload umbilicals and releasing the latches retaining the Tug in the Orbiter bay The next crew action is the rotation of the Tug by the docking adapter to an angle where the payload end of the Tug is above the Orbiter bay opening At this point the crew extends and mates the RMS with the Tug The Tug/Orbiter RF telemetry and command link is then established and verified With the verification of the Tug/Orbiter RF communications and all other systems ready the Orbiter Crew releases the Tug from the docking adapter and guides the Tug out of the Orbiter bay with the RMS until the RMS is fully extended With concurrence from the Tug Operations Center, the Orbiter will

release the Tug from the RMS and initiate the Orbiter evasive maneuver At separation from the RMS, the Tug software will initiate active APS to maintain attitude hold while the Orbiter maneuvers to a safe distance The steerable antenna will search and detect the TDRS and establish downlink telemetry. When the Orbiter has maneuvered to a safe distance Tug control will be relinquished to the ground

3.2 2 1 6 Enable Tug Systems

The command to enable the remaining Tug systems will be issued by the Tug Operation Center (TOC) with the Orbiter crew providing backup capability The enable command will be issued after the Orbiter crew has relinquished control of the Tug to the TOC. The acceptance of the Command by the Tug will initiate the preprogrammed attitude maneuver for this time period and will institute the activation of the main propulsion system

3 2 2 1 7 Check and Verify Tug Systems

The Tug systems checks will nominally be conducted by automatic sequence controlled by the Tug DMS The test sequence data will be telemetered and monitored by TOC personnel who will have command options at their disposal for unexpected or suspect condition investigation Alternate plans may be implemented if malfunctions are detected

3 2.2 1 8 Mission Enable

If no perturbations occur during the on orbit initialization and checkout of the Tug, then the Tug mission sequence will be enabled by either the DMS or by TOC command At this time the DMS will enter the on orbit coast mode in preparation for the first main engine burn

3 2 2 2 On-Orbit Coast Module

The On-Orbit Coast Module provides the interim on orbit navigation guidance and control state between active mission modules. During these waiting periods the overall mission plan can be reviewed and modified to accommodate real time mission variations The duration of time spent in this module will be a function of the sequenced mission schedule maintained by the DMS in the Tug flight program. During this mode the navigation update sequence and on-orbit mission planning sequence may be entered by ground command or as a result of special conditions for handling unscheduled but necessary mission changes. Figure 3 2 2-2 is a flow diagram showing the module functional capability and the potential interface with other modules Table 3 2.2-2 is a listing of the major Tug and TOC events contained in this module.

3 2 2 2 1 On-Orbit Guidance Navigation and Control

The On-Orbit GN&C Module provides for the maintenance of the Tug attitude and trajectory during the periods between mainstage, trimburns, target rendezvous and docking, payload placement, service, retrieval and Orbiter retrieval. If a navigation update is required the sequence can be commanded and accomplished during this time

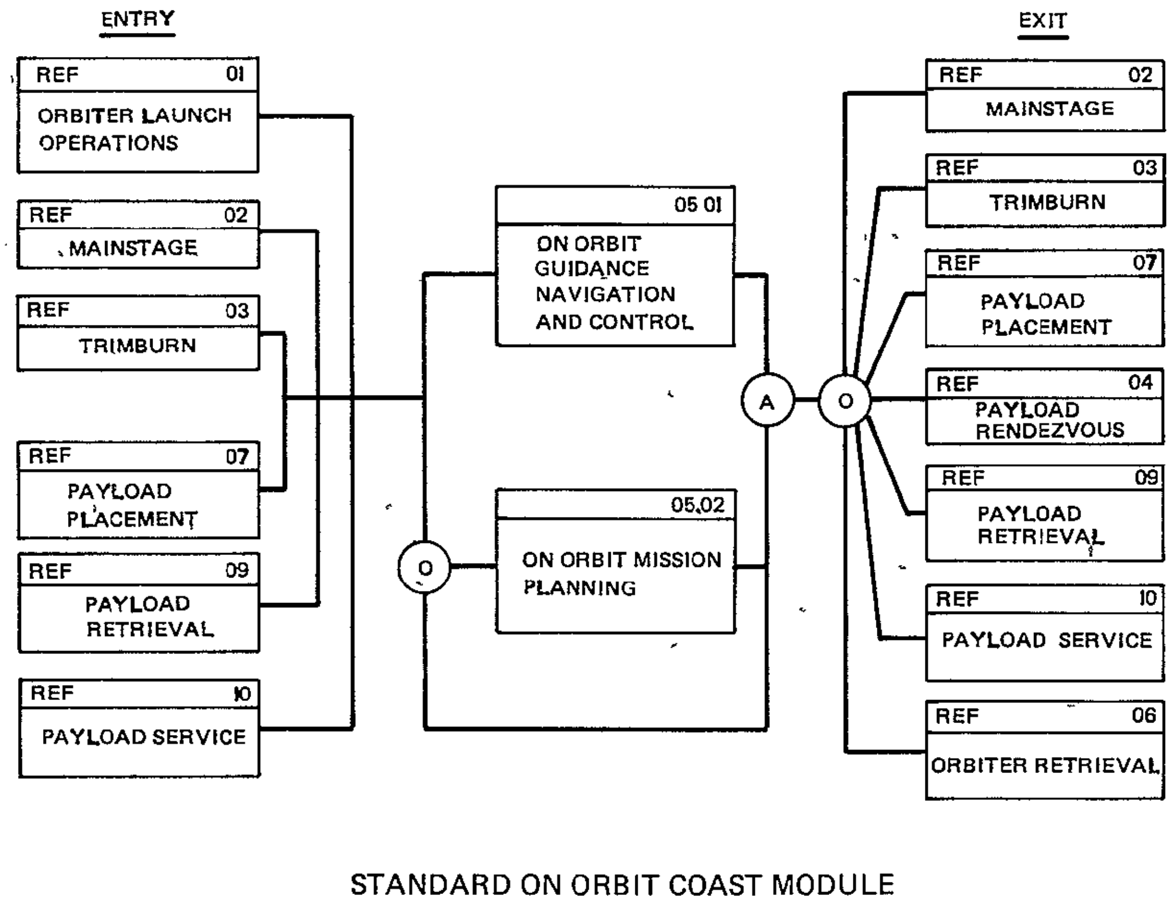


Figure 3 2 2-2 Standard On-Orbit Coast Module

3 2 2 2 2 On-Orbit Mission Planning

The nominal mission will not require any adjustment in the preplanning sequence of events However, should major perturbations occur, such as missed first mainstage opportunity, early engine cutoff or anything negating the nominal sequence, then the capability exists through this function to change, by reloading the DMS, the mission sequence in a manner best suited to the current realtime conditions

3 2 2 3 Mainstage Module

The Mainstage Module is utilized each time the Tug must make a major maneuver such as a phasing burn, transfer orbit burn, large midcourse correction, and/or circularization This module is entered with the Tug in the on orbit coast mode and exits to the on orbit coast mode after accomplishing the desired major thrusting maneuver Nominal time in the module as currently defined is composed of approximately fifteen minutes preburn preparations, the burn maneuver, and three minutes post burn operations. Figure 3 2 2-3 depicts by flow chart the major function sequence within the module Table 3 2 2-3 lists the major Tug and TOC events and their respective times

Table 3 2.2-2 Standard On-Orbit Coast Module

STANDARD ON ORBIT COAST MODULE (05)

The on orbit coast module provides the interim on orbit navigation guidance and control state between active mission modules During these waiting periods the overall mission plan can be reviewed and modified to accomodate realtime mission variations

ENTRY Orbiter Launch Operation, Mainstage, Trimburn, Payload Placement, Payload Service, and Payload Retrieval

EXIT Mainstage, Trimburn, Payload Placement, Rendezvous, Payload Service, Payload Retrieval, and Orbiter Retrieval

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)	Event time in minutes (Reference Time; 1 2 3 4 5)
<u>ON ORBIT GN&C</u>	01 00				
ON ORBIT NAVIGATION	01 01				
ON ORBIT ATTITUDE CONTROL	01 02				
MONITOR TUG SYSTEMS	01 03				
TRACK SPACE TUG	01 04				
MAINTAIN TUG EPHEMERIS	01 05				
MAINTAIN TARGET EPHEMERIS	01 06				
MONITOR CONSUMABLES USAGE	01 07				
NAVIGATION UPDATE AS REQUIRED	01 08	00 017			
TARGET UPDATE AS REQUIRED	01 09	00 017			
ATTITUDE UPDATE AS REQUIRED	01 10	00 017			
<u>ON ORBIT MISSION PLANNING</u>	02 00	00 083			
COMPUTE 1ST AND 2ND OPPORTUNITY TARGET PARAMETERS	02 01	00 017			
COMPUTE 1ST AND 2ND OPPORTUNITY BURN PARAMETERS	02 02	00 017			
PLAN OPTIMUM MISSION EVENT SEQUENCE FOR 1ST AND 2ND OPPORTUNITY	02 03	00 017			
VERIFY 1ST AND 2ND OPPORTUNITY PARAMETERS AND EVENT SEQUENCE MEMORY LOAD	02 04	00 033			

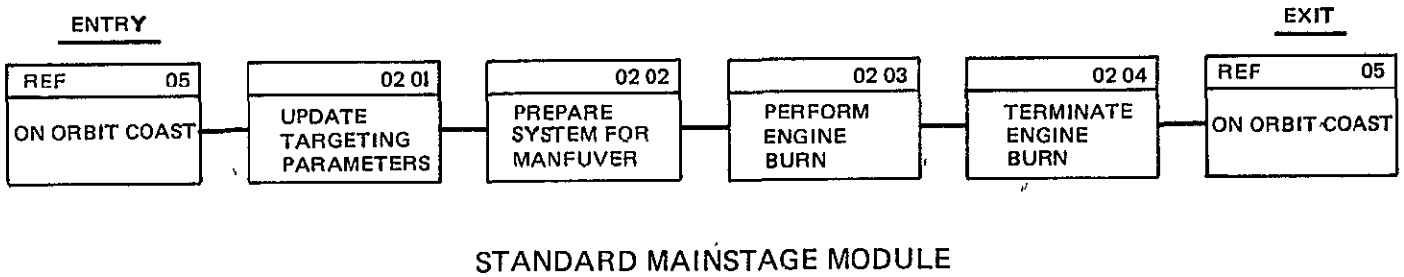


Figure 3 2 2-3 Standard Mainstage Module

Table 3 2.2-3 Standard Mainstage Module

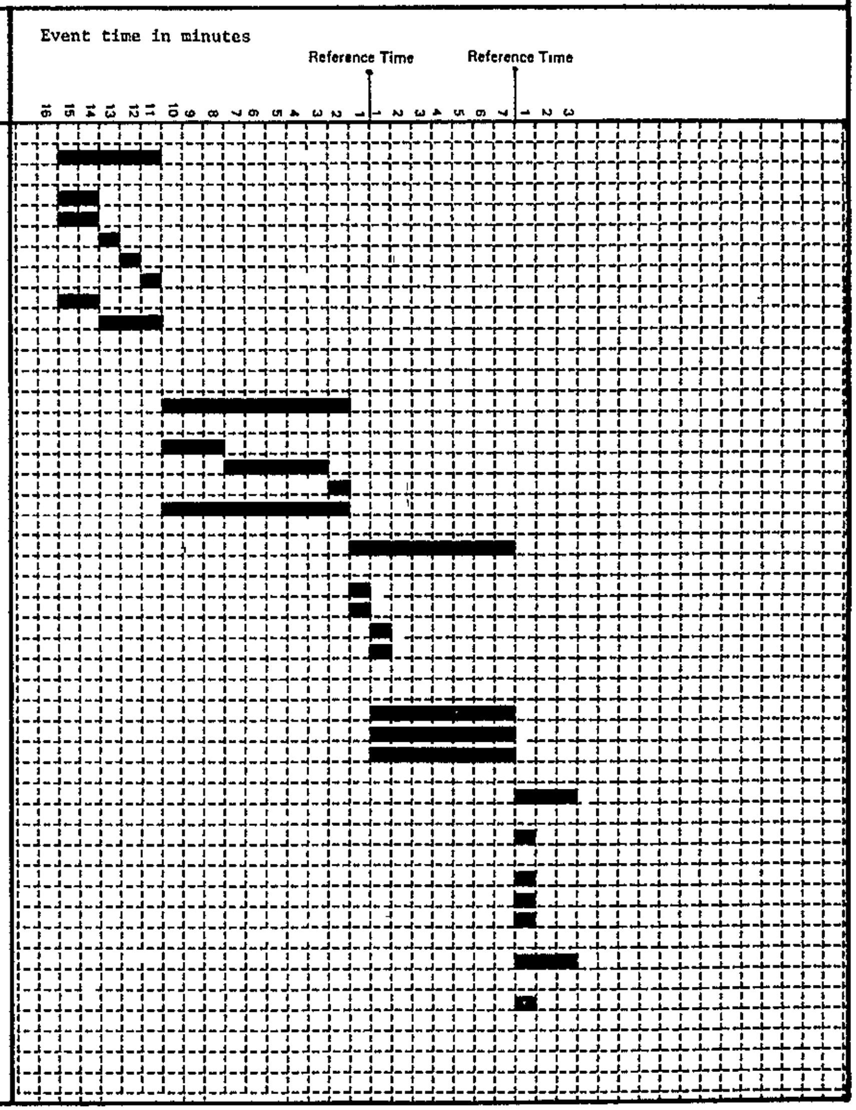
STANDARD MAINSTAGE MODULE (02)

The mainstage module is utilized each time the Space Tug must make a major maneuver such as a phasing burn, transfer orbit burn, large mid-course correction, circularization, etc This module is entered with the Space Tug in the on-orbit coast mode and exits in the on-orbit coast mode after the accomplishment of the desired major thrusting maneuver.

ENTRY On Orbit Coast

EXIT On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
UPDATE TARGETING PARAMETERS	01 00	00 083	- 0 250	
EVALUATE ORBIT AND TRAJECTORY	01 01	00 033	- 0 250	
EVALUATE GN&C SYSTEM	01 02	00 033	- 0 250	
NAVIGATION UPDATE	01 03	00 017	- 0 217	
ATTITUDE UPDATE	01 04	00 017	- 0 200	
TARGET UPDATE	01 05	00 017	- 0 183	
EVALUATE PROPULSION & MASS STATUS	01 06	00 033	- 0 250	
CALCULATE ORBIT CHANGE MANEUVER AND UPLINK CHANGES TO TUG MISSION PLAN	01 07	00 050	- 0 217	
PREPARE SYSTEM FOR MANEUVER	02 00	00 150	- 0 167	
MANEUVER TO BURN ATTITUDE	02 01	00 050	- 0 167	
ALL SYSTEMS TO BURN CONFIGURATION	02 02	00 083	- 0 117	
START BURN LOGIC SEQUENCE	02 03	00 017	- 0 033	
MONITOR AND COMMAND STANDBY	02 04	00 150	- 0 167	
PERFORM ENGINE BURN	03 00	00 133	- 0 017	
INITIATE BURN SEQUENCE	03 01	00 017	- 0 017	
INITIATE MAINSTAGE GN&C	03 02	00 017	- 0 017	
START ENGINE	03 03	00 017	REF	
NO IGNITION (REVERT TO ON ORBIT NAVIGATION AND SELECT 2ND OPPORTUNITY MISSION PLAN)	03 04	00 017	0 017	
MONITOR EVENT SEQUENCE	03 05	00 116	0 133	
GROUND BACKUP ENGINE CUTOFF COMMAND	03 06	00 116	0 133	
INITIATE AND PERFORM BURN TRACKING	03 07	00 116	0 133	
TERMINATE BURN	04 00	00 050	0 000	
CALCULATE AND ISSUE ENGINE CUTOFF (TUG SOFTWARE)	04 01	00 017	REF	
TELEMETER BURN DATA	04 02	00 017	0 000	
EXIT SEQUENCE TO ON ORBIT NAVIGATION	04 03	00 017	0 000	
MONITOR CUTOFF AND PROVIDE GROUND BACKUP ENGINE CUTOFF COMMAND	04 04	00 017	0 000	
COMPARE CALCULATED AND ACTUAL BURN DATA	04 05	00 050	0 000	
INITIATE COAST TRACKING	04 06	00 017	0 000	



3 2 2 3 1 Update Targeting Parameters

This five minute portion of the module permits the evaluation of the trajectory and a navigation and target update if required The calculations for the burn attitude and start and stop times are accomplished by the Tug flight program

3 2 2 3 2 Prepare Systems for Maneuver

This sequence occurs immediately prior to the main engine burn The Tug is oriented by the APS to the proper attitude for burn initialization The main propulsive system is configured for engine ignition

3 2 2 3 3 Perform Engine Burn

At approximately one minute prior to engine ignition the burn sequence is entered and the mainstage GN&C is initiated If the scheduled mainstage ignition should fail to occur, the flight program will terminate the burn sequence and revert to the on orbit coast mode For the first mainstage burn, a second opportunity sequence will be resident in the flight program and will be automatically implemented if required

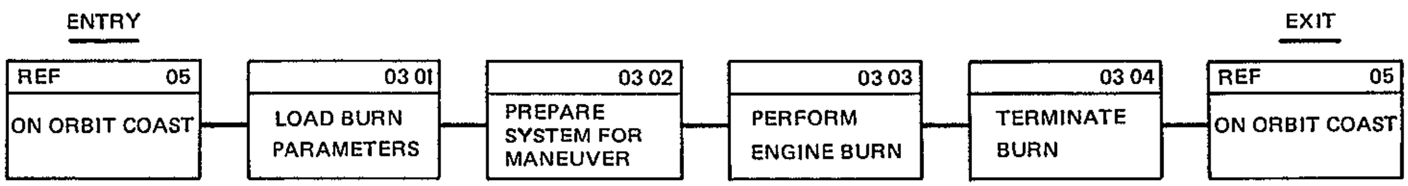
Prior to mainstage ignition, the TOC will initate burn tracking if tracking is part of the operations system and will also monitor and verify the on board events as they occur During the active mainstage burn, the TOC will monitor the vehicle events, and trajectory and provide backup engine cutoff through the command system

3 2 2 3 4 Terminate Burn

The terminating sequence for engine burn has been allowed three minutes in the timeline but should occur at a more rapid pace The main engine cutoff will be calculated and issued by the flight program and the terminal burn parameters telemetered The TOC will provide backup engine cutoff capability The TOC will terminate burn tracking and evaluate the burn end conditions to determine if burn objectives have been met The flight program will automatically exit to the on orbit coast mode where mission plans can be modified and a trim burn scheduled if required

3 2 2 4 Trimburn Module

The Trimburn Module is utilized whenever the main engine is operated in the tankhead idle or in the pump mode or when the APS is utilized for minor orbit corrections As with the Mainstage Module, the Trimburn Module is entered from the on orbit coast mode and exists to the on orbit coast mode after completion of the desired thrusting Nominal time allowed in the timeline for initiating a trimburn maneuver is approximately ten minutes plus the duration of the burn and three minutes for burn termination Figure 3 2 2-4 illustrates the flow of the major functions within the module Table 3 2 2-4 lists the major Tug, TOC events and their respective times



STANDARD TRIMBURN MODULE

Figure 3 2 2-4 Standard Trimburn Module

Table 3.2 2-4 Standard Trimburn Module

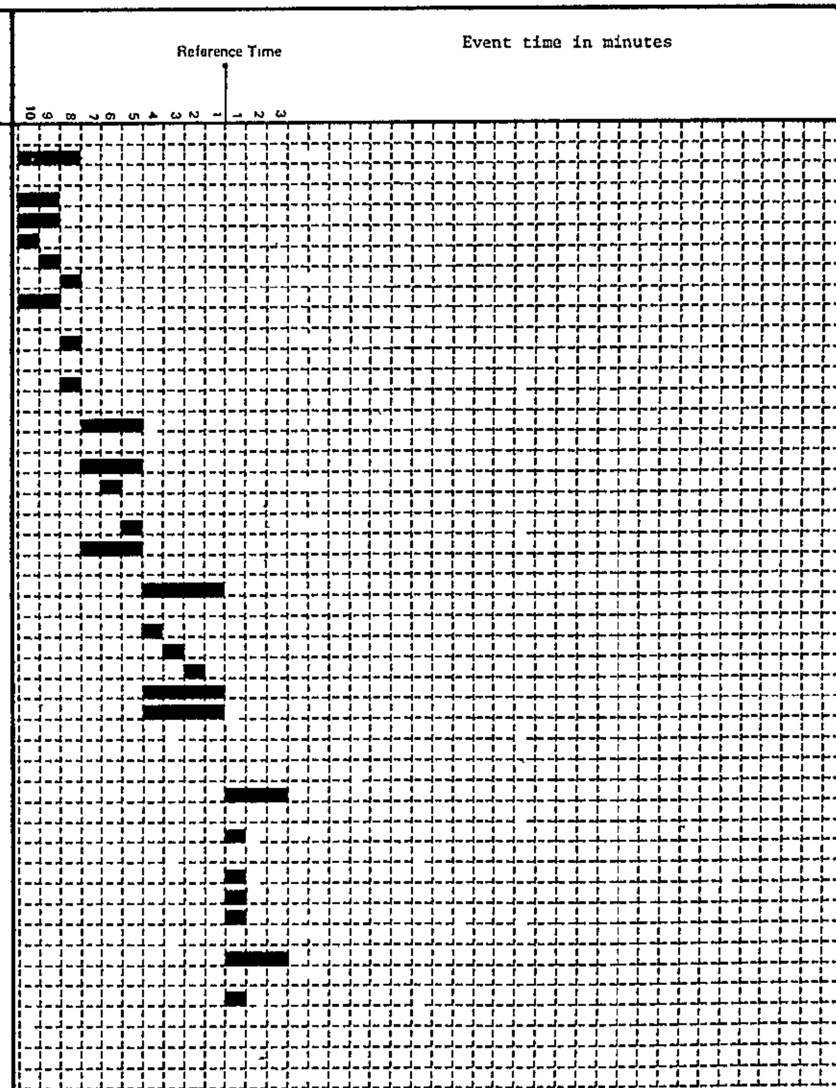
STANDARD TRIMBURN MODULE (03)

The trim burn module is utilized whenever the main engine is operated in the tank-head idle or in the pump mode or when the APS system is utilized for minor orbit corrections As with the main stage module, the trim burn module is entered from the on-orbit coast mode and exits to the on-orbit coast mode after completion of the desired thrusting.

ENTRY On Orbit Coast

EXIT On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
LOAD BURN PARAMETERS	01 00	00 050	0 167	
EVALUATE ORBIT AND TRAJECTORY	01 01	00 033	0 167	
EVALUATE GN&C SYSTEM	01 02	00 033	0 167	
NAVIGATION UPDATE	01 03	00 017	0 167	
ATTITUDE UPDATE	01 04	00 017	0 150	
TARGET UPDATE	01 05	00 017	0 133	
CALCULATE TRIMBURN MANEUVER PARAMETERS	01 06	00 033	0 167	
SELECT TRIM BURN MODE (PUMP, THI, or APS)	01 07	00 017	0 133	
SELECT EVENT SEQUENCE	01 08	00 017	- 0 133	
PREPARE SYSTEM FOR MANEUVER	02 00	00 050	- 0 117	
MANEUVER TO BURN ATTITUDE	02 01	00 050	- 0 117	
ALL SYSTEMS TO TRIM BURN CONFIGURATION	02 02	00 017	- 0 100	
START TRIMBURN LOGIC SEQUENCE	02 03	00 017	- 0 083	
MONITOR AND COMMAND STANDBY	02 04	00 050	- 0 117	
PERFORM ENGINE BURN	03 00	00 067	- 0 067	
INITIATE BURN SEQUENCE	03 01	00 017	- 0 067	
INITIATE TRIM BURN GN&C	03 02	00 017	- 0 050	
START TRIM BURN THRUST	03 03	00 017	- 0 033	
MONITOR EVENT SEQUENCE AND COMMAND STANDBY	03 04	00 067	- 0 067	
INITIATE AND PERFORM TRIMBURN TRACKING	03 05	00 067	- 0 067	
TERMINATE BURN	04 00	00 050	REF	
CALCULATE AND ISSUE ENGINE CUTOFF (TUG SOFTWARE)	04 01	00 017	0 000	
TELEMETER BURN DATA	04 02	00 017	0 000	
EXIT SEQUENCE TO ON ORBIT COAST	04 03	00 017	0 000	
MONITOR CUTOFF AND PROVIDE GROUND BACKUP ENGINE CUTOFF COMMAND	04 04	00 017	0 000	
COMPARE CALCULATED AND ACTUAL BURN DATA	04 05	00 050	0 000	
INITIATE COAST TRACKING	04 06	00 017	0 000	



3 2 2 4 1 Load Burn Parameters

This sequence of events permits the incorporation of a preburn navigation target and attitude update if desired The calculation of burn attitude, burn start and stop time, and burn select (Pump, Tank Head Idle (THI) or APS) is also accomplished in the on orbit coast mode and will be deleted from this time frame if not required

3 2 2 4 2 Prepare Systems for Maneuver

This sequence immediately precedes the trimburn thrust maneuver. The Tug is oriented by the APS to the trimburn attitude If the main propulsion system is to be utilized, it is readied for the selected burn mode (Pump or THI)

3 2 2 4 3 Perform Engine Burn

Just prior to the initiation of trimburn thrust the Tug flight program initiates Trimburn GN&C The GN&C used during this state will vary depending on the thrust mode employed If the use of tracking is planned the TOC will start burn tracking and monitor burn performance

3 2 2 4 4 Terminate Burn

The terminate sequence for the trimburn maneuver will be similar to that employed by the Mainstage Module. The burn cutoff will be calculated and issued by the the flight program and the TOC will provide backup command cutoff capability. Burn end condition data will be telemetered to the TOC for evaluation and the sequence will exit to the on orbit coast mode

3 2 2 5 Payload Placement Module

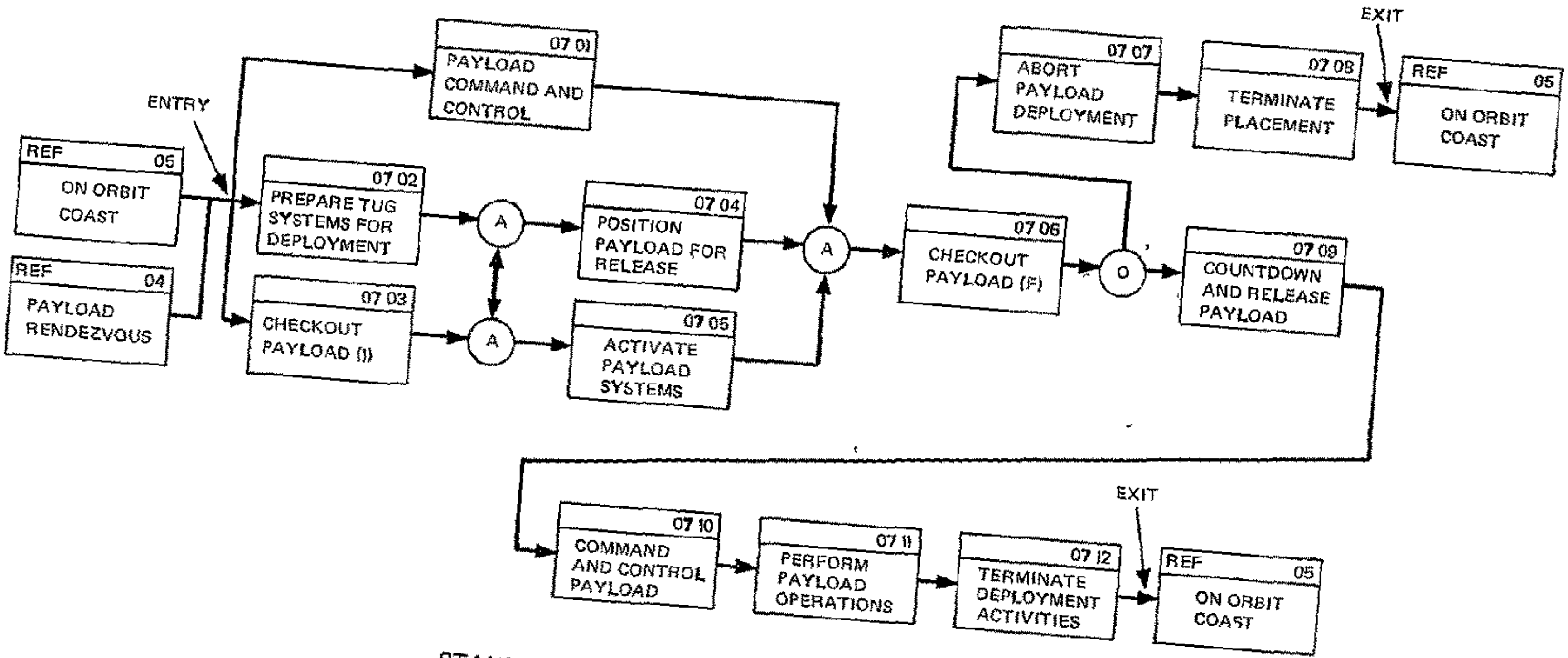
The Payload Placement Module incorporates the activities required to check out and deploy a Spacecraft After phasing away from the deployed Spacecraft the Tug enters the on orbit coast or Docking Module depending on the mission. In the case where the mission requirement is to rendezvous with an existing on orbit Spacecraft before deployment of the Tug payload, the rendezvous can be accomplished, the on board payload deployed, and the Docking Module entered before the on orbit Spacecraft is retrieved Figure 3 2.2-5 is a flow diagram showing the module functional capabilities and interfaces with other modules Table 3 2 2-5 is a listing of payload placements events and their respective duration times

3 2 2 5 1 Payload Command and Control

During this sequence of events the Spacecraft to be deployed is initialized and enabled to accept commands Critical parameters are available through Tug telemetry for ground control observation

3 2 2 5 2 Prepare Tug Systems For Deployment And Checkout Of Payload

The Tug will maneuver to the appropriate attitude for checkout of the Spacecraft Checkout of the Spacecraft will be initiated by the DMS and conducted by automatic sequence Should a malfunction occur it will be possible to safe



STANDARD PAYLOAD PLACEMENT MODULE

Figure 3 2 2-5 Standard Payload Placement Module

Table 3 2 2-5 Standard Payload Placement Module

STANDARD PAYLOAD PLACEMENT MODULE (07)

The payload placement module defines the activities required to checkout and deploy a satellite, leaving the Space Tug in the on-orbit coast mode phasing away from the deployed satellite

ENTRY On Orbit Coast, Rendezvous

EXIT On Orbit Coast, Docking

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
PAYLOAD COMMAND AND CONTROL	01 00	00 133	- 0 433	
INITIALIZE PAYLOAD SYSTEMS	01 01	00 050	- 0 433	
ENABLE COMMAND ACCEPT	01 02	00 017	- 0 417	
SEQUENCE PAYLOAD CHECKOUT	01 03	00 100	- 0 417	
MONITOR MISSION CRITICAL PARAMETERS	01 04	00 117	- 0 417	
DEPLOYMENT ABORT LOGIC	01 05	00 117	- 0 417	
PREPARE TUG SYSTEMS FOR DEPLOYMENT	02 00	00 083	- 0 417	
ACTIVATE DOCKING SYSTEM	02 01	00 017	- 0 417	
MANEUVER TO CHECKOUT ATTITUDE	02 02	00 067	- 0 417	
CALL CHECKOUT SOFTWARE	02 03	00 033	- 0 417	
PREPARE MECHANICAL LATCH UNLOCK	02 04	00 033	- 0 417	
CALL STANDBY DYNAMICS SOFTWARE	02 05	00 067	- 0 417	
CHECKOUT PAYLOAD (INITIAL)	03 00	00 050	- 0 400	
INITIATE CHECKOUT ROUTINE	03 01	00 017	- 0 400	
MONITOR STATUS	03 02	00 050	- 0 400	
COMMUNICATE STATUS	03 03	00 033	- 0 383	
POSITION PAYLOAD FOR RELEASE	04 00	00 067	- 0 383	
MANEUVER TO DEPLOYMENT ATTITUDE	04 01	00 050	- 0 383	
MOVE MECHANISM TO READY	04 02	00 033	- 0 367	
ACTIVATE PAYLOAD SYSTEMS	05 00	00 083	- 0 367	
DEPLOY SOLAR PANELS (AS REQ'D)	05 01	00 067	- 0 367	
DEPLOY P/L ANTENNAE (AS REQ'D)	05 02	00 067	- 0 367	
PAYLOAD ON INTERNAL POWER	05 03	00 017	- 0 367	
PAYLOAD ATTITUDE CONTROL STANDBY	05 04	00 017	- 0 367	
PAYLOAD NAVIGATION SYSTEM GO	05 05	00 017	- 0 350	
LOAD NAVIGATION DATA	05 06	00 050	- 0 333	
PAYLOAD SELF-SUFFICIENT	05 07	00 017	- 0 317	
CHECKOUT PAYLOAD (FINAL)	06 00	00 083	- 0 250	
CALL FINAL CHECKOUT SOFTWARE	06 01	00 033	- 0 250	
MONITOR STATUS	06 02	00 083	- 0 250	
INITIATF CHECKOUT ROUTINE	06 03	00 083	- 0 250	
COMMUNICATE STATUS	06 04	00 067	- 0 233	

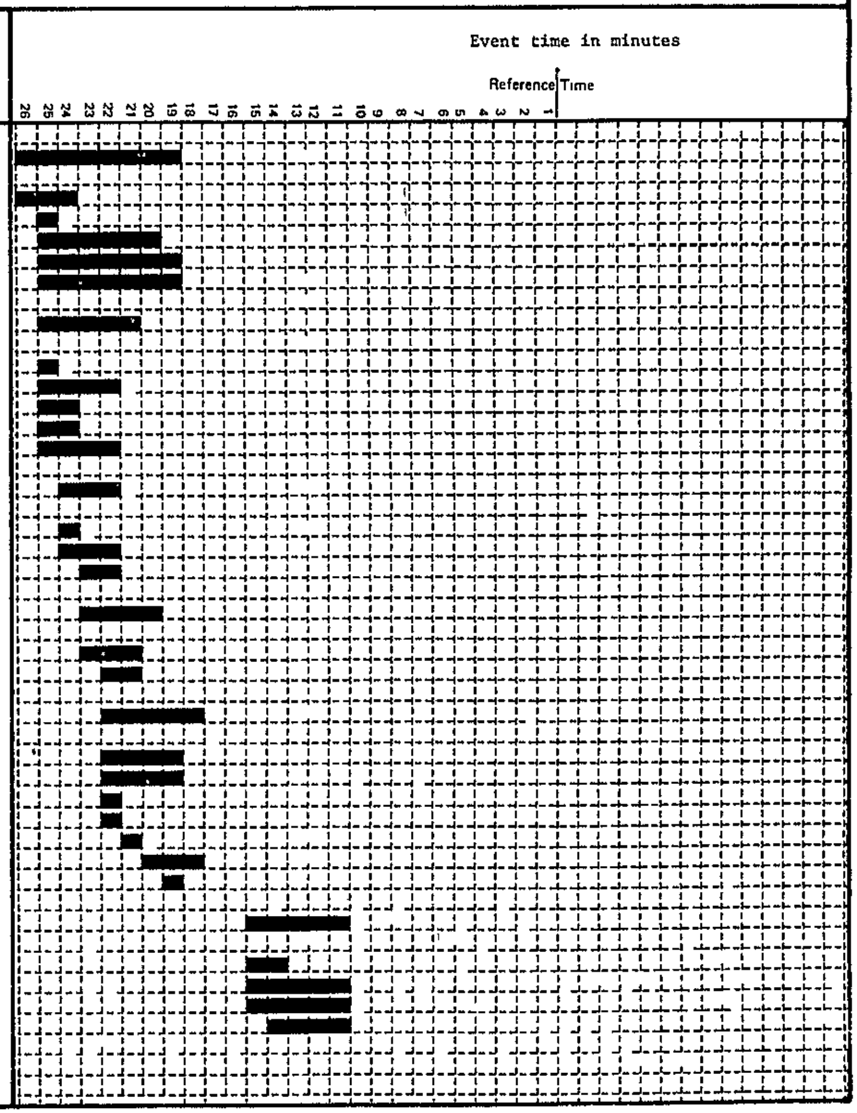


Table 3 2 2-5 Standard Payload Placement Module (Continued)

STANDARD PAYLOAD PLACEMENT MODULE (07)(CONTINUED)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
ABORT PAYLOAD DEPLOYMENT	07 00	00 117	- 0 233	
RECEIVE NO-GO FROM FINAL CHECKOUT	07 01	00 017	- 0 233	
CALL DE-ACTIVATION SOFTWARE	07 02	00 033	- 0 233	
SEQUENCE DOWN PAYLOAD SYSTEMS	07 03	00 050	- 0 217	
INITIATE ALTERNATE MISS. SEQUENCE	07 04	00 100	- 0 217	
RETRACT LATCHES TO 'HARD DOCK	07 05	00 017	- 0 200	
COMMUNICATE STATUS	07 06	00 083	- 0 200	
TERMINATE PLACEMENT	08 00	00 067	- 0 183	
SECURE ALL PAYLOAD SYSTEMS	08 01	00 050	- 0 183	
JETTISON ALL PROTURBANCES	08 02	00 050	- 0 183	
CONFIGURE TO COAST MODE	08 03	00 050	- 0 167	
COUNTDOWN & RELEASE PAYLOAD	09 00	00 200	- 0 150	
INITIATE COUNTDOWN SEQUENCE	09 01	00 150	- 0 150	
ACHIEVE DESIRED RELEASE POINT	09 02	00 067	- 0 133	
ENABLE PAYLOAD ATTITUDE CONTROL	09 03	00 167	- 0 117	
DETACH MECH & ELEC UMBILICALS	09 04	00 033	- 0 100	
SPIN-UP PAYLOAD (IF REQUIRED)	09 05	00 050	- 0 083	
RELEASE CAPTURE LATCHES	09 06	00 033	- 0 033	
ACTIVATE TV MONITOR	09 07	00 083	- 0 033	
RELEASE FINAL LATCHES	09 08	00 017	REF	
BACK OUT AND STATION KEEP	09 09	00 050	0 000	
COMMAND AND CONTROL PAYLOAD	10 00	00 117	0 017	
ESTABLISH TWO-WAY RF COMMUNICATION	10 01	00 050	0 017	
FLY AROUND PAYLOAD	10 02	00 117	0 017	
PERFORM VISULA INSPECTION	10 03	00 117	0 017	
MONITOR PAYLOAD PARAMETERS	10 04	00 067	0 067	
COMMAND VERNIER MANEUVERS	10 05	00 067	0 067	
PERFORM JOINT PAYLOAD OPERATIONS	11 00	00 117	0 083	
COMMAND PAYLOAD SEQUENCES	11 01	00 100	0 083	
CONDUCT JOINT TUG/PAYLOAD OPERATIONS	11 02	00 083	0 100	
TURN OVER CONTROL TO POC	11 03	00 017	0 183	

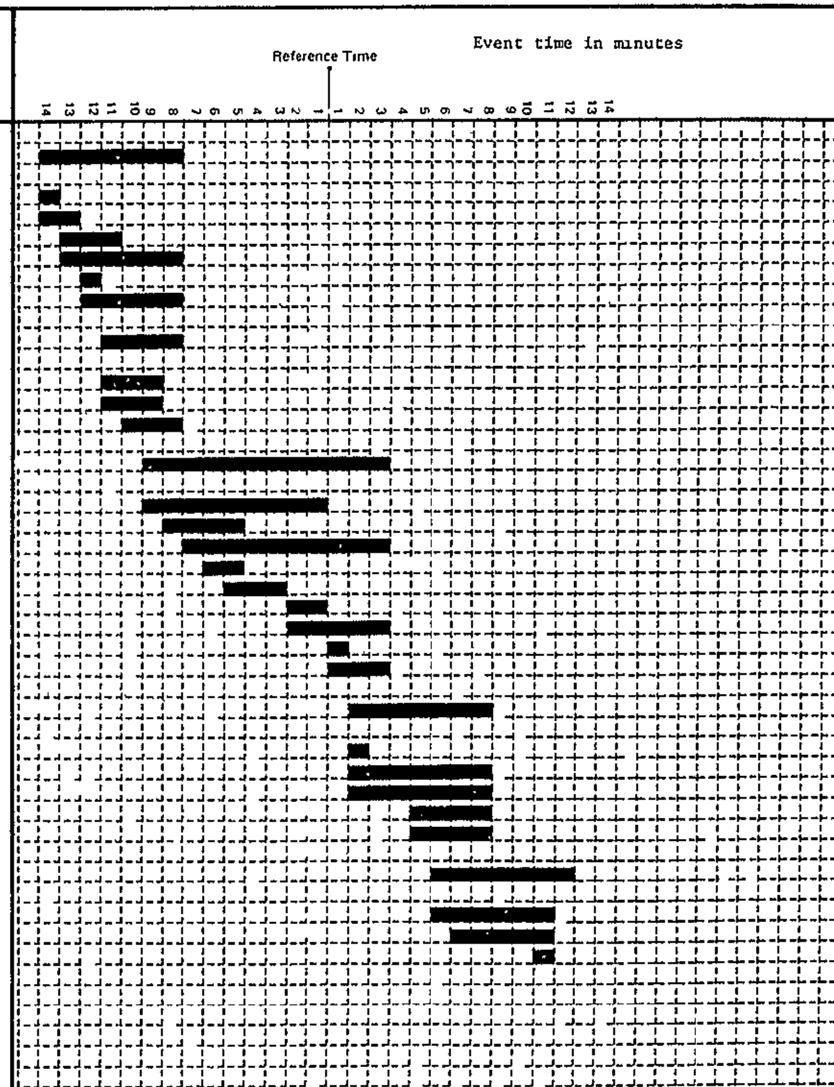


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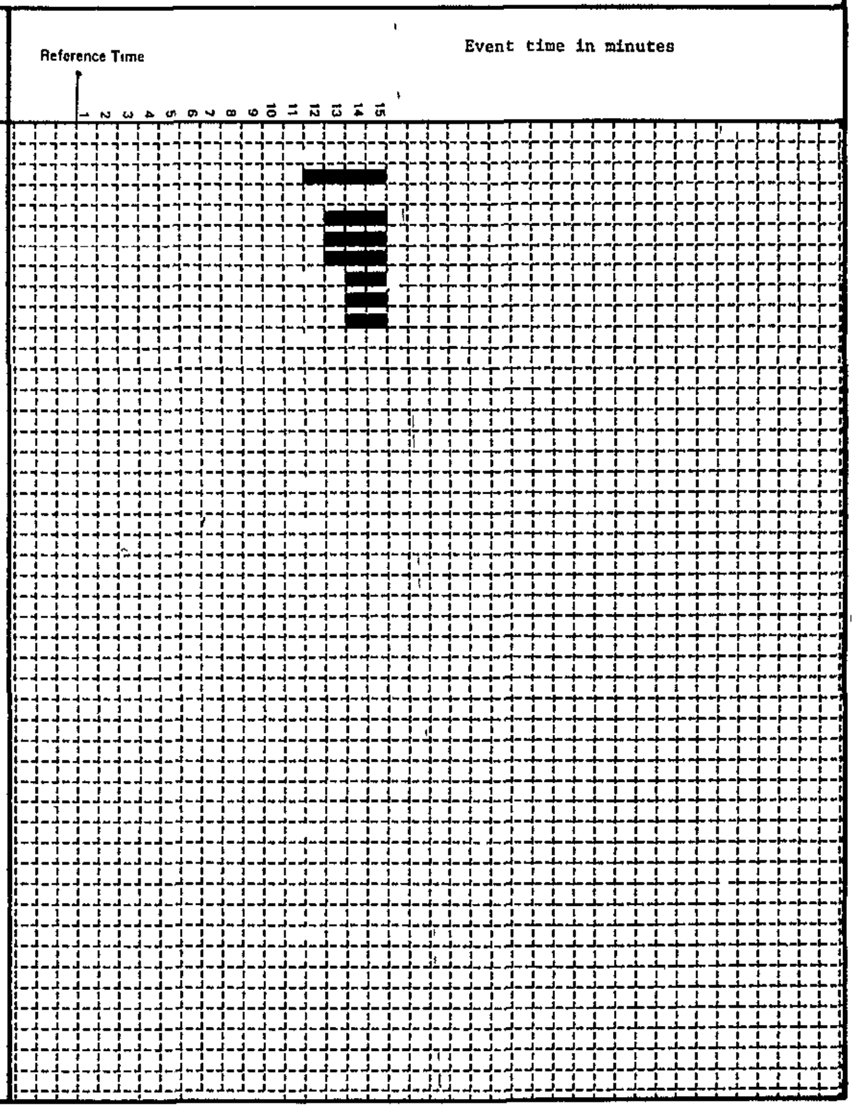
Table 3 2 2-5 Standard Payload Placement Module (Continued)

STANDARD PAYLOAD PLACEMENT MODULE (07) (CONTINUED)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
TERMINATE DEPLOYMENT ACTIVITIES	12 00	00 067	0 200	
PERFORM PHASING BURN	12 01	00 050	0 217	
MONITOR PAYLOAD VIA TV	12 02	00 050	0 217	
DEACTIVATE DOCKING SYSTEM	12 03	00 050	0 217	
CONFIGURE TO COAST MODE	12 04	00 033	0 233	
DEACTIVATE TV	12 05	00 033	0 233	
COMMUNICATE STATUS	12 06	00 033	0 233	



the Spacecraft and return with the Tug to the Orbiter if mission plans and propellant supplies allow With checkout complete the Tug will then maneuver to the proper attitude for deployment and the final activation of Spacecraft checks may be conducted at this time Again the placement of the Spacecraft may be aborted at this time if a malfunction is detected

3 2 2 5 3 Countdown And Release Of Payload

The final sequence for release will depend on the type of Spacecraft but will generally be accomplished by releasing the holding latches and a slow withdrawal maneuver executed by the Tug Prior to release all electrical and other connections will be severed and for some, Spacecraft spin up will be required After withdrawal to a safe distance and with a constant separation rate in progress, the Tug will enter the on-orbit coast mode

3 2 2 6 Rendezvous Module

The Rendezvous Module defines the operations required for the Tug to move from a coplanar phasing orbit to a point sufficiently near a target Spacecraft for docking to be initiated The component submodules are Rendezvous Acquisition, Terminal Phase Initiating (TPI), and Terminal Phase Transfer (TPT) Figure 3 2 2-6 is a flow diagram showing the module functional capability and interfaces Table 3 2 2-6 is a listing of Tug, Spacecraft, and TOC events comprised in this module

3 2 2 6 1 Rendezvous Acquisition

During this submodular operation, the rendezvous tracker search is implemented, the Spacecraft is acquired and tracked and the Tug stage vector is updated to be consistent with the tracking information from the previously uplinked Spacecraft vector

3 2 2 6 2 Terminal Phase Initiation

This submodule is defined separately from Terminal Phase Transfer because the main engine will be employed in TPI All targetting calculations for selecting the transfer-arc geometry as well as the burn parameters for producing that transfer arc are calculated in TPI Following this a standard Trimburn Module, described in Section 3 2 2 4 is implemented

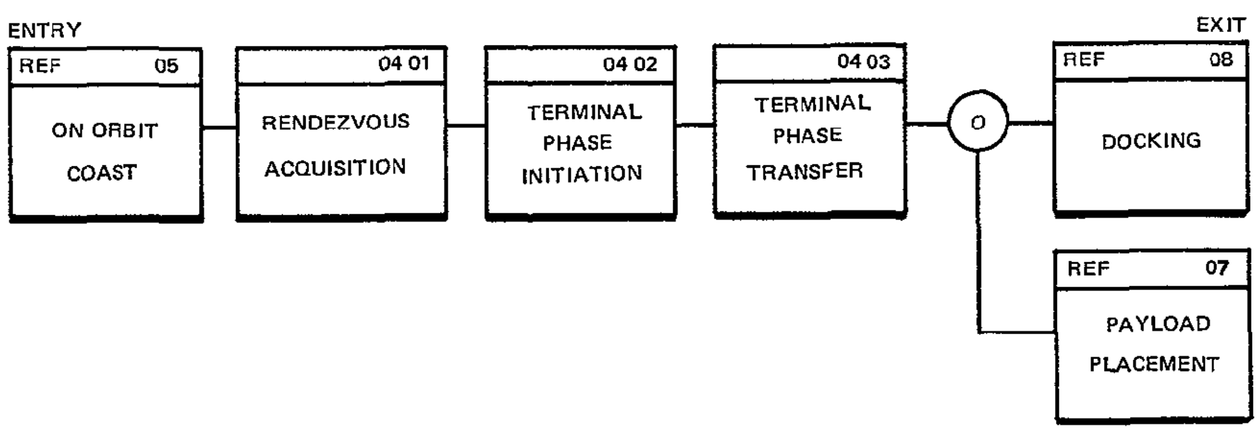


Figure 3 2 2-6 Standard Rendezvous Module

Table 3 2.2-6 Standard Rendezvous Module

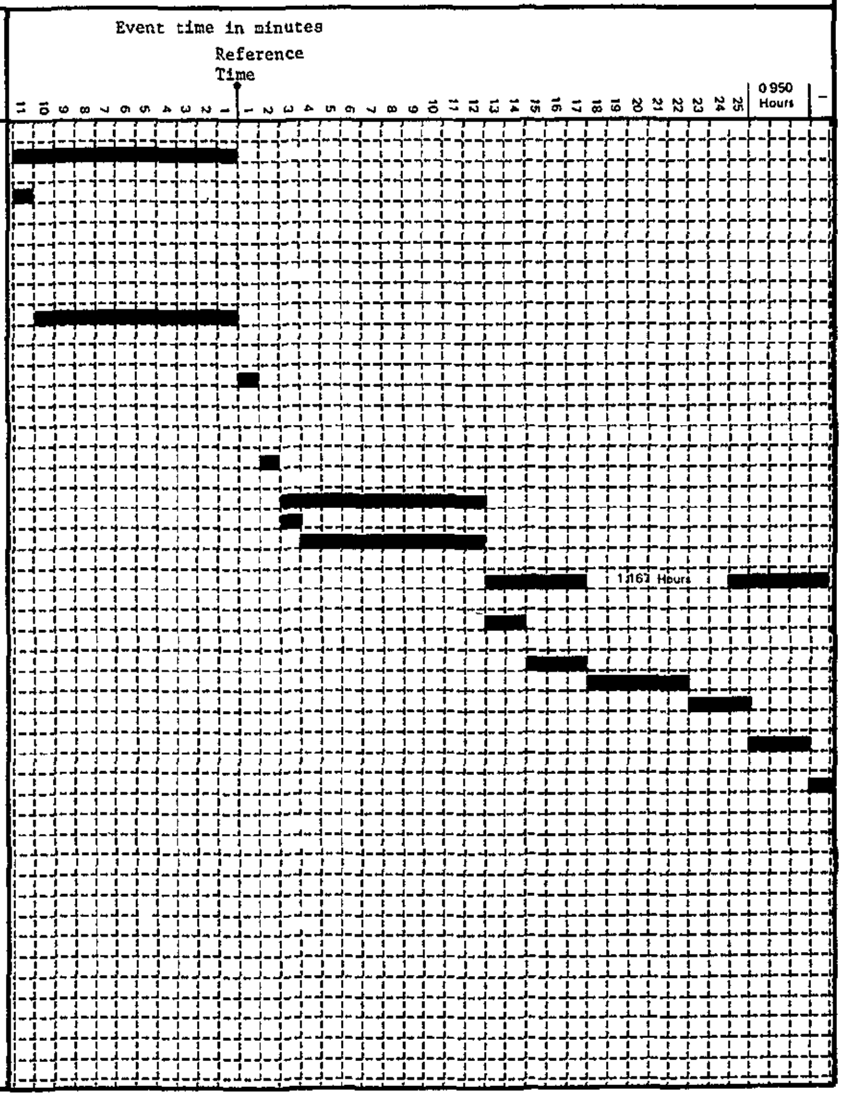
STANDARD RENDEZVOUS MODULE (04)

The Rendezvous Module contains the events associated with the initial contact and closing maneuvers between the Tug and spacecraft with which the Tug is to dock Included is acquisition, terminal phase initiation and the orbital transfer to a range sufficiently small for docking to commence

ENTRY On Orbit Coast

EXIT Docking, Payload Placement

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
RENDEZVOUS ACQUISITION	01 00	0 183	- 0 183	
TARGET EPHEMERIS UPDATE (VIA UPLINK), DETERMINATION OF INITIAL VECTOR TO TARGET AND ACTIVATE RENDEZVOUS SENSOR	01 01	0 017	- 0 183	
VALIDATE SENSOR, SEARCH FOR TARGET	01 02	0 167	- 0 167	
ACQUIRE TARGET, VALIDATE DIFFERENCE OF VECTOR FROM PREDICTION	01 03	0 017	REF	
UPDATE TARGET EPHEMERIS	01 04	0 017	0 017	
TERMINAL PHASE INITIATION	02 00	0 167	0 033	
CALCULATE RENDEZVOUS PARAMETERS	02 01	0 017	0 033	
PERFORM TRIM BURN	02 02	0 150	0 050	
TERMINAL PHASE TRANSFER	03 00	1 167	0 217	
MANEUVER TO PARALLEL LONGITUDINAL AXIS TO LINE OF SIGHT	03 01	0 033	0 217	
REACQUIRE SPACECRAFT	03 02	0 050	0 250	
VALIDATE TRANSFER TRAJECTORY	03 03	0 083	0 300	
TRANSFER ORBIT COAST TRIM BURN IF REQUIRED (TANK HEAD IDLE)	03 04	0 050	0 383	
TRANSFER ORBIT COAST, INITIAL SEARCH WITH DOCKING SENSORS	03 05	0 933	0 433	
ACTIVATE ACS TRANSLATIONAL CONTROL SYSTEM AT THE TRANSITION GATE	03 06	0 017	1 366	



3 2 2 6 3 Terminal Phase Transfer

This module contains the balance of rendezvous following TPI The Tug will be pointed directly toward the Spacecraft and will track it throughout TPT unless the attitude must be changed for trimming the trajectory or braking prior to initiating docking procedures Early in the transfer, if tracking defines significant error, one or more small-impulse trimburns will be implemented The range and required impulse for at least two braking gates will be calculated following each trim-burn and will be periodically updated as transfer-arc dispersions are identified by rendezvous tracking

3 2 2 7 Docking Module

The Docking Module defines the operations executed by the Tug from the last braking gate until latching with the target Spacecraft has occurred The submodules include inspection and alignment, closure, and terminal docking Two significant differences from rendezvous are the requirements that the Tug maneuvers relative to the Spacecraft attitude and Tug maneuvering is not constrained by orbital mechanics Figure 3 2 2-7 illustrates the module flow diagram and Table 3 2 2-7 is a list of events comprised in the module

3 2 2 7 1 Inspection And Alignment

Following the last braking at the exit from Rendezvous, the Tug will continue closing with the target Spacecraft but now under phase-plane translational control referenced to the target Upon reaching the preset minimum safe non-docking range, the locus of which forms a safety sphere, the Tug will circumnavigate the target Spacecraft to support televised inspection by the TOC and SCOC During this phase the docking tracker is searching for the docking-aid reflectors mounted on the Spacecraft Circumnavigation will comprise a set of mutually perpendicular orbits followed by another set until the TOC commands the Tug to proceed with alignment and the docking aids are acquired and being tracked

3 2 2 7 2 Closure

The closure submodule contains the lateral and closure translation required to align the Tug to the target docking axis at the commit range, which is the range just greater than that at which the track of the peripheral reflectors is lost preventing relative attitude determination If a hold command has not been received from the TOC and if the lateral attitude errors are within docking latch tolerances, the Tug transitions smoothly into the next operational module, Terminal Docking

3 2 2 7 3 Terminal Docking

The fixed-attitude closure down the docking axis at the optimum contact speed, the initial and final latches and the establishment of the umbilical interfaces are included in Terminal Docking Range, range rate and lateral displacement error are determined from the information derived from tracking the central docking-aid reflector A failure to execute initial latch at impact will cause the Tug to automatically revert to the Commit Range and await an enabling command before attempting to re-dock

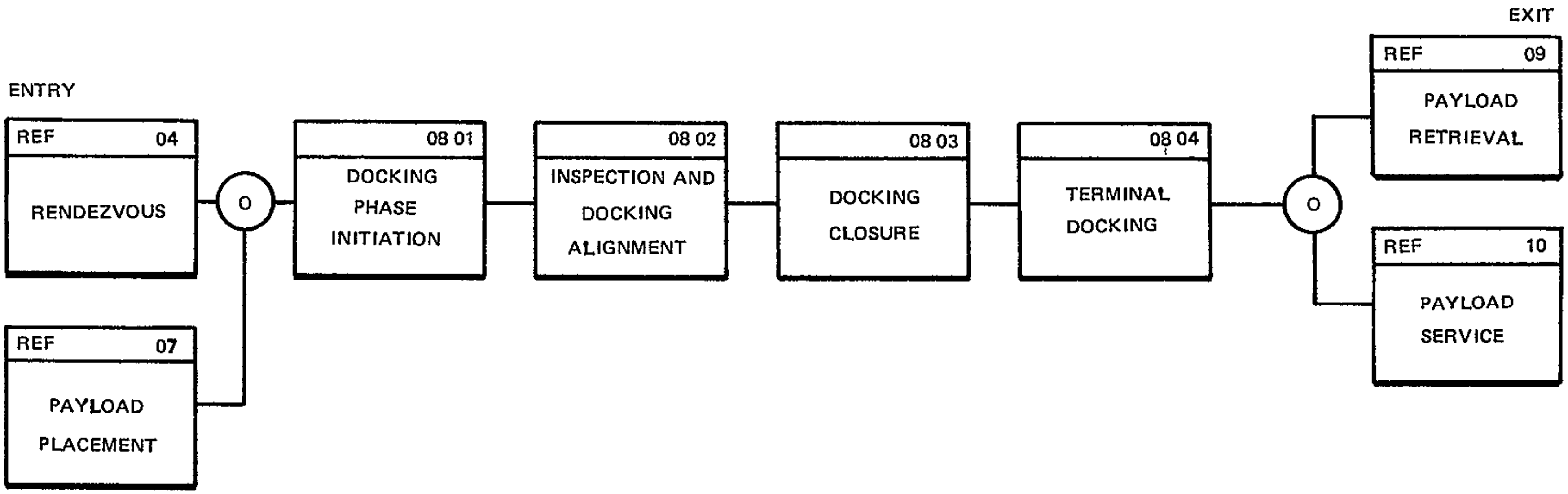


Figure 3 2 2-7 Standard Docking Module

Table 3 2 2-7 Standard Docking Module

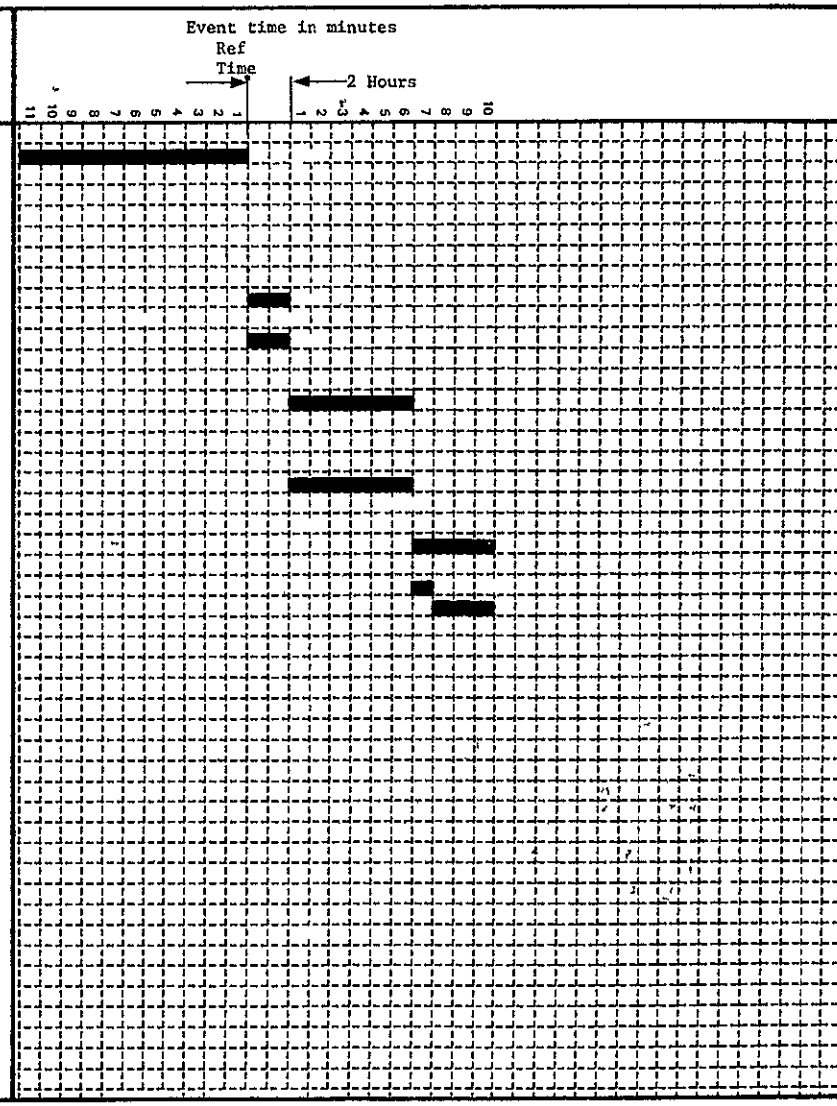
STANDARD DOCKING MODULE (08)

The Docking Module contains the events for maneuvering relative to a subject spacecraft and docking with it

ENTRY Rendezvous, Payload Placement

EXIT Payload Retrieval, Service

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
DOCKING PHASE INITIATION	01 00	0 183	- 0 183	
CONTINUE CLOSURE	01 01			
CONTINUE DOCKING AID SEARCH	01 02			
TERMINATE AT TARGETTED MINIMUM SAFE APPROACH RANGE	01 03			
INSPECTION AND DOCKING ALIGNMENT	02 00	2 000	0 000	
CIRCUMNAVIGATE THE TARGET FOR INSPECTION AND DOCKING PORT LOCATION	02 01	2 000	REF	
CLOSURE	03 00	0 100	2 000	
DOCKING AID ACQUIRES DOCKING TARGET (PRE-CONDITION)	03 01	0 000	2 000	
CLOSE TO BE ON AXIS AT THE DOCKING SENSOR MINIMUM RANGE	03 02	0 100	2 000	
TERMINAL DOCKING	04 00	0 067	2 100	
CLOSE TO PORT	04 01	0 017	2 100	
LATCH TO TARGET, MATE UMBILICAL, VERIFY MECHANICAL AND ELECTRICAL INTEGRITY	04 02	0 050	2 117	



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3.2 2 8 Payload Retrieval Module

The Payload Retrieval Module is initiated after payload docking and passivation has been accomplished. The function of the module is to secure the retrieved payload for return to the Orbiter by the Tug Figure 3 2 2-8 illustrates that the module is entered from the Docking Module and exits to On-Orbit Coast Module Table 3.2 2-8 lists the sequence of events which prepare the payload for the return to the Orbiter

3 2 2 8 1 Inert Payload

After docking, the retrieved payload transmitters are deactivated and any pressurants, propellants, or other active agents safed Safing could involve a dumping operation If continuous power is necessary for payload maintenance, power transfer to the Tug will be performed. Appendages will be retracted and stored and the payload will be secured for return to the Orbiter

3 2 2 9 Standard Service Module

Baseline Tug System Requirements and Guidelines specify requirements for Tug capability to service Spacecraft including those which are spin-stabilized and those launched as multiple payloads Service concept capabilities selected as a basis for generation of the Standard Service Module include

- television, (two dimensions only)
- modular Spacecraft with modules designed for on-orbit substitution
- replacement of modules by manipulator or indexing mechanism
- manipulator capable of providing mechanical "assists" to Spacecraft
- servicer docking interface to Spacecraft capable of spin/despin
- servicer/Tug capability of providing thermal support to Spacecraft
- servicer/Tug capability of providing power, data systems and communication system support to Spacecraft

Figure 3 2 2-9 illustrates, in the central portion of the figure, the functional flow of Tug servicing of Spacecraft The major events are designated SSM (Standard Service Module) one through six The upper portion of this figure shows how the Standard Service Module fits within the Standard Docking Module to implement docking with, and repair of, the malfunctioning Spacecraft. The lower portion of the Figure shows how the servicing function fits within the Standard Payload (Spacecraft) Placement Module to define the re-deployment of Spacecraft after servicing Notice that the Standard Docking Module as a whole fits within the Standard Payload Placement sequence between Events SPPM 10 and SPPM 11 This provides for the recovery and service or re-service of a Spacecraft which fails its post deployment checkout, Event SPPM 10 Table 3 2 2-9 defines each of the six major events in the Standard Service Module by naming the sub-events, their durations, their start times referenced to Event 1 0, and the graphical representation of their relative timing relationships The reference point for calculation of times within the

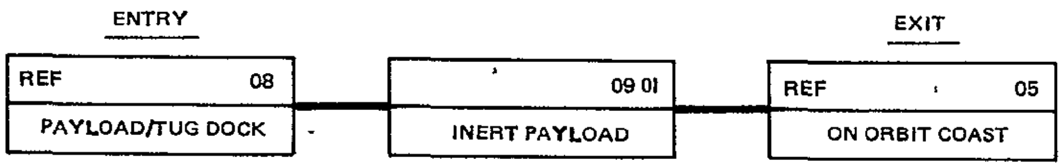


Figure 3.2.2-8. Standard Payload Retrieval Module

mission is the moment when latch is achieved between the Tug and the Spacecraft to be serviced when the Standard Service Module is being entered from the Standard Docking Module When entered from the Standard Payload Placement Module, the Standard Service Module beginning time (reference time) is the termination of Standard Payload Placement Module Event 6, "Checkout Payload (Spacecraft)" under conditions when checkout criteria were not met and the need for servicing was identified Under these circumstances, the Orbiter, Tug, and Payload conditions in effect at the time checkout was aborted and servicing was begun may obviate some or all of the preparations for servicing operations which are otherwise scheduled in Events SSM 1, SSM 2, and SSM 3 In such instances, the unnecessary steps are bypassed and the reference time for the start of the Standard Service Module is adjusted appropriately

3 2 2 9.1 Prepare Tug For Servicing Operations

After the Tug and Spacecraft are docked and latched, reorientation is begun immediately if required to satisfy Spacecraft requirements for such reasons as thermal control, power generation, or communications Communications and Telemetry links which are required for servicing operations are established and Tug/SC umbilicals are connected Critical performance parameters are checked through the DMS for a coarse check on the advisability of continuing the servicing operation If the decision is made to continue, the Spacecraft is despun (if required), otherwise other decisions are made as to the disposition of the Spacecraft, possibly leading to its jettisoning The only Spacecraft in the present baseline which requires despin is the Large Radio Observatory with a spin rate of 1/60 rpm so a despin time of 10 minutes has been allowed in the timeline (The requirement for despin capability in the servicer might possibly be obviated for presently baselined payloads by requiring the Large Radio Observatory to despin itself by such means as RCS) For Spacecraft which require it, the Tug provides thermal conditioning while servicing continues A closed circuit television inspection of the Spacecraft is performed leading to a decision to abort servicing or to continue by configuring the Tug for service operations Any Spacecraft passivation required is then completed, meanwhile, subsystem support to the Spacecraft is initiated and any reaction wheel braking required is provided Two hours have been allowed for active braking of reaction wheels If braking is not required by the Spacecraft, the time needed to prepare the Tug for Servicing can be approximately cut in half (from just over two hours) One hour has been allowed for checkout of replacement modules before their installation in the Spacecraft so this begins about an hour into the servicing operation if braking is required, otherwise it would begin when Spacecraft passivation is completed Just before servicing operations are to begin, the Servicer and Manipulator are checked out At this point the Tug is verified as being ready to begin scheduled service operations and this is reported to the ground

Table 3 2 2-8 Standard Payload Retrieval Module

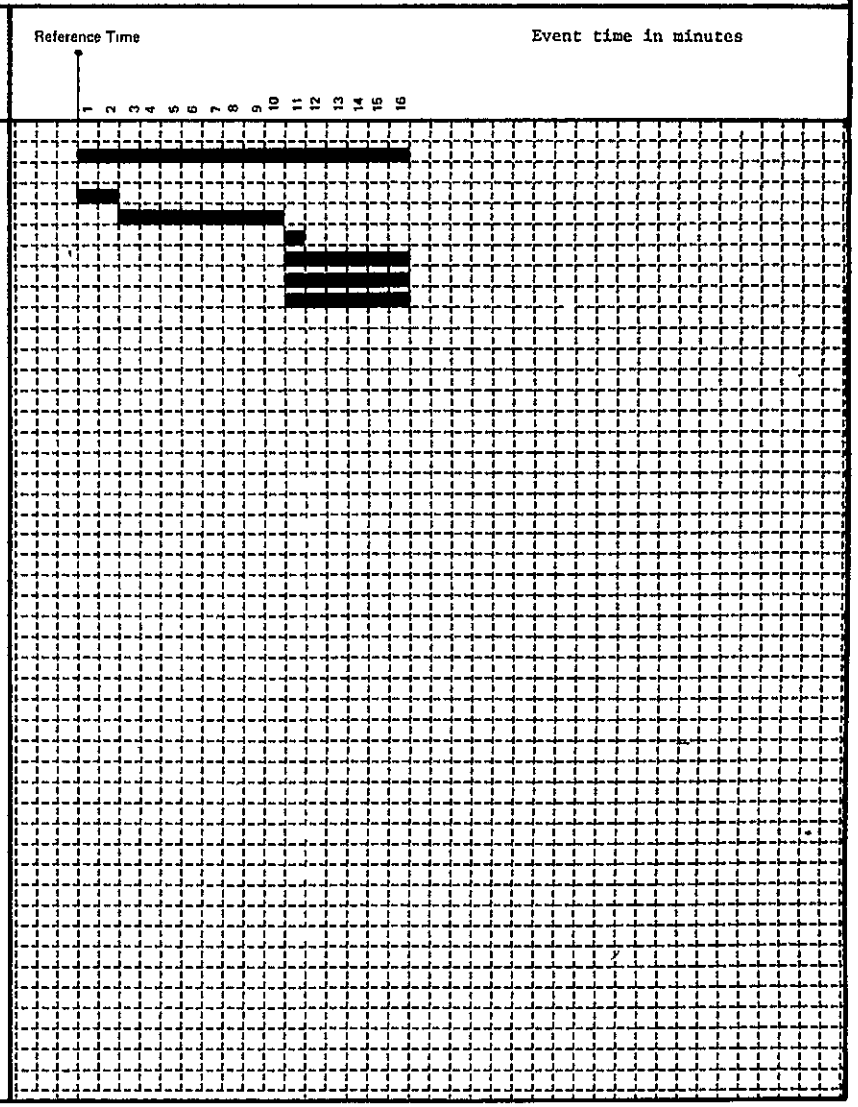
STANDARD PAYLOAD RETRIEVAL MODULE (09)

The payload retrieval module is initiated after payload docking and passivation has been accomplished The function of the module is to secure the retrieved payload for return to the Orbiter with the Tug

ENTRY Payload/Tug Dock

EXIT On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
INERT PAYLOAD	01 00	00 267	0 000	
DEACTIVATE TRANSMITTERS	01 01	00 033	0 000	
SAFE PROPELLANTS, PRESSURANTS	01 02	00 133	0 033	
TRANSFER PWR TO EXTERNAL (TUG PWR)	01 03	00 017	0 183	
CONFIGURE P/L FOR RETURN	01 04	00 083	0 183	
STOW APPENDAGES	01 05	00 083	0 183	
VERIFY P/L SYSTEM "GO" FOR RETURN	01 06	00 083	0 183	



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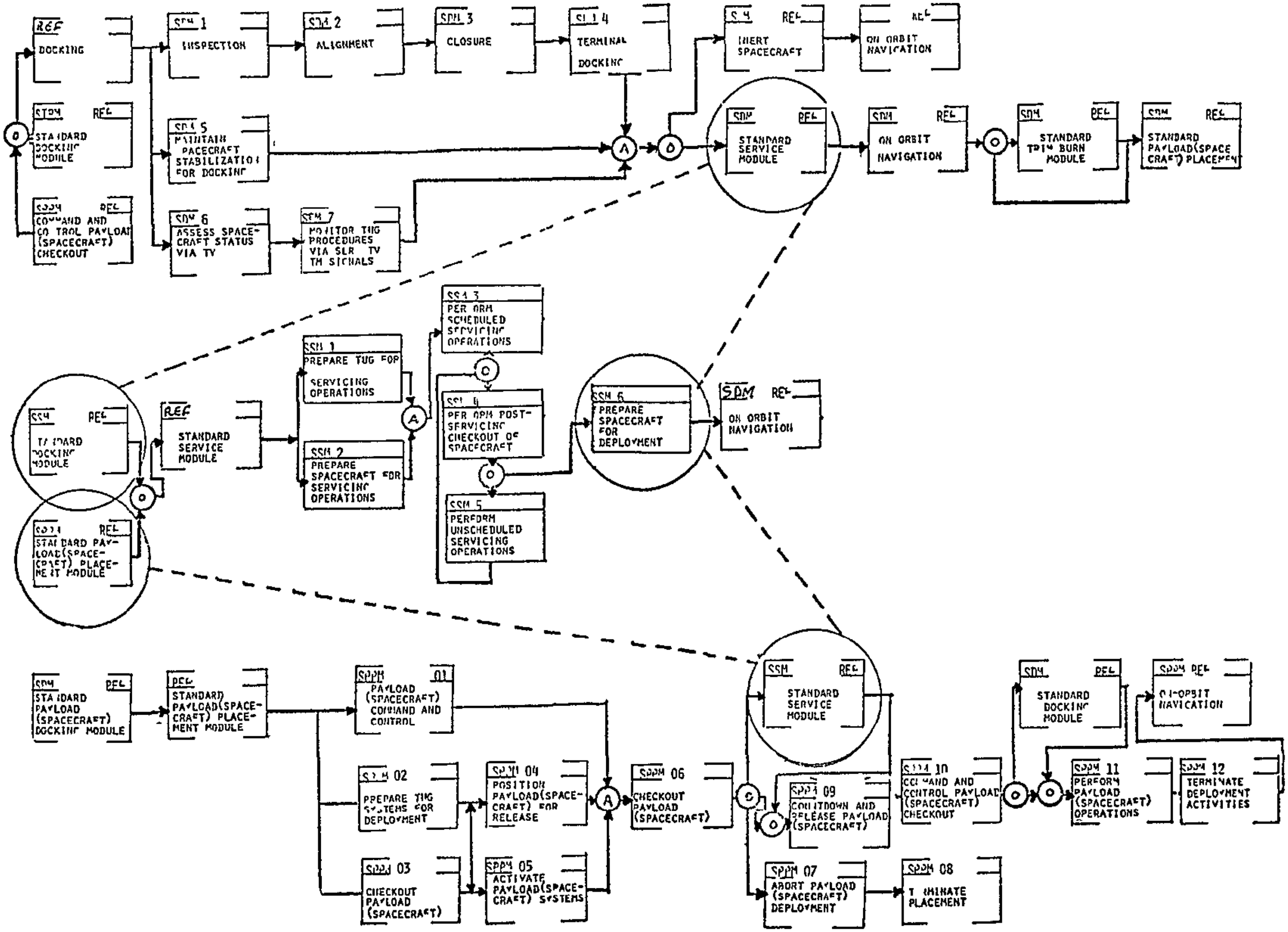


Figure 3.2.2-9 Standard Service Module

Table 3.2.2-9 Standard Service Module

STANDARD SERVICE MODULE (10)

The Service Module performs the exchange of modules within the spacecraft and the activation and checkout of the serviced spacecraft

ENTRY Docking

EXIT On Orbit Coast Payload Placement

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
PREPARE TUG FOR SERVICING OPS.	1 0	2 124	000	
ORIENT TUG/SC FOR RF, THERM.,PWR.	1 1	083	000	
VERIFY RF,COM, & TM LINKS TO GND.	1 2	083	000	
CONNECT TUG/SC UMBILICALS	1 3	017	066	
MONITOR CRITICAL PARAMETERS	1 4	008	075	
DESPIN SPACECRAFT IF REQUIRED	1 5	167	083	
PROVIDE THERMAL CONDITIONING TO SC	1 6	2 000	083	
INSPECT SPACECRAFT BY CCTV	1 7	083	208	
CONFIGURE TUG FOR SERVICING,VERIFY	1 8	050	291	
COMPLETE SC PASSIVATION IF REQ'D.	1 9	167	167	
PROVIDE SUBSYSTEM SUPPORT TO SC,	1 10	2,000	083	
BRAKE SC REACTION WHEELS IF REQ'D	1 11	2 000	083	
CHECK OUT SERVICER & MANIPULATOR	1 12	083	2 000	
CHECK OUT REPLACEMENT MODULES	1 13	1 000	1 083	
TAKE ENGINEERING DATA ON TUG & SC	1 14	033	2 083	
VERIFY TUG READY FOR SERVICING	1 15	083	2 033	
REPORT STATUS TO GROUND	1 16	008	2 116	
PREPARE SPACECRAFT FOR SERVICING	2 0	2 025	066	
MONITOR CRITICAL PARAMETERS	2 1	008	066	
DESPINNING BY TUG/SERVICER IF REQD	2 2	167	083	
REC. THERMAL CONDITIONING SUPPORT	2 3	2 000	083	
INSPECTION BY TUG CCTV	2 4	083	208	
ACTIVATE SUBSYSTEMS	2 5	008	250	
CONFIGUR SC FOR SERVICING OPER.	2 6	083	250	
COMPLETION OF PASSIVATION IF REQD	2 7	167	250	
REACTION WHEEL BRAKING/STOPPING	2 8	2 000	083	
CHECK/VERIFY MODULES FOR REPLACE.	2 9	1 000	417	
TAKE FRAME OF ENGINEERING DATA	2 10	033	1 417	
DEACTIVATE SC SUBSYSTEMS	2 11	008	1 450	
UNLATCH/LATCH MODULES	2 12	067	1 933	
VERIFY SC READY FOR SERVICING	2 13	083	2 000	
REPORT STATUS TO GROUND	2 14	008	2 083	
PERFORM SCHEDULED SERVICE OPER.	3 0	500	2 091	
MONITOR CRITICAL PARAMETERS	3 1	008	2 091	
POSITION CCTV TO OBSERVICE SERVICE	3 2	050	2 099	
ACTUATE SERVICER, REPLACE MODULES	3 3	333	2 167	
CHECK CONTINUITY OF MODULES	3 4	333	2 250	
REPORT STATUS TO GROUND	3 5	008	2 583	

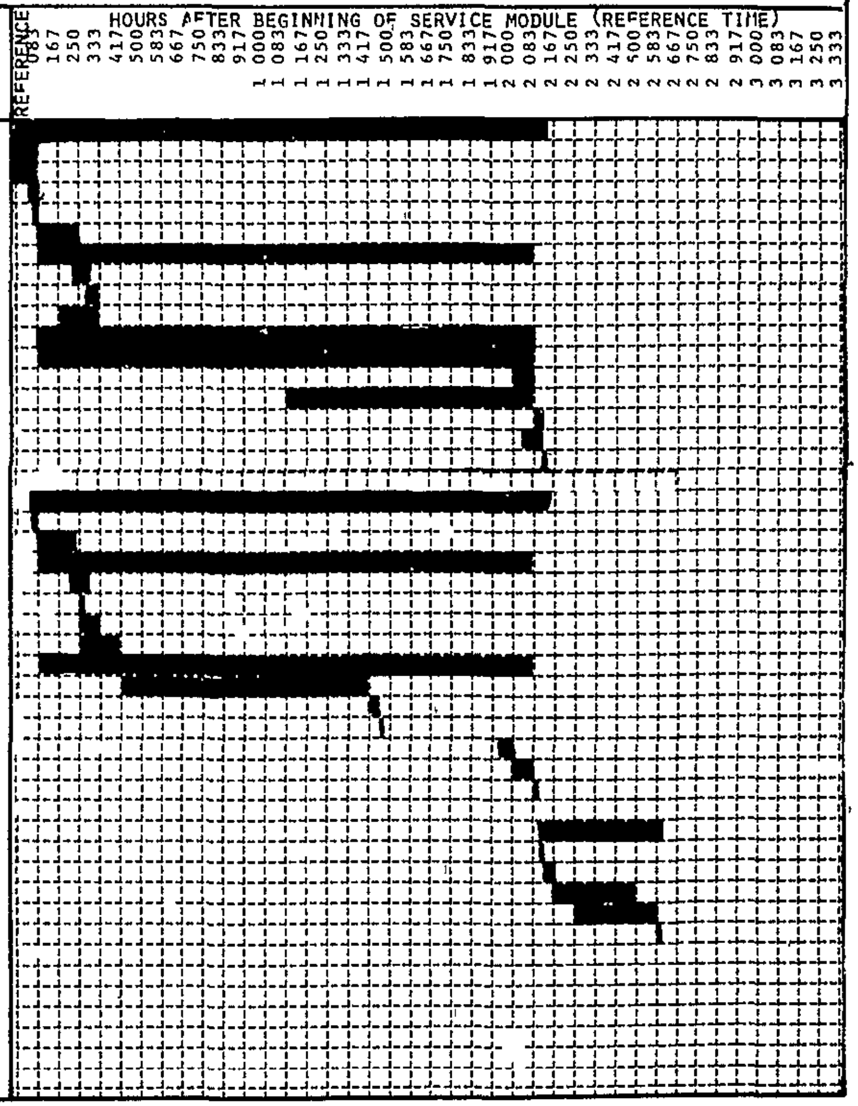
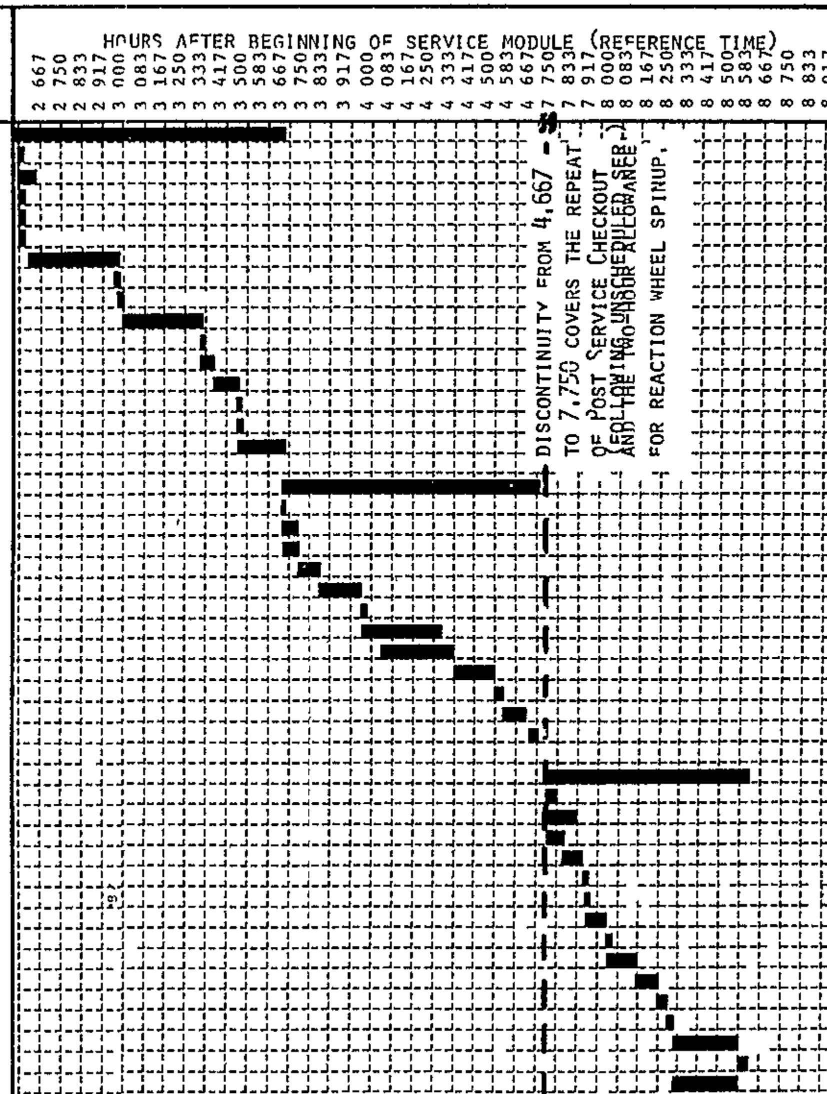


Table 3.2 2-9 Standard Service Module (Continued)

STANDARD SERVICE MODULE (Continued)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
POST-SERVICE CHECKOUT OF SC	4 0	1 047	2 591	
MONITOR CRITICAL PARAMETERS	4 1	008	2 591	
POSITION CCTV TO OBSERVE CHECKOUT	4 2	05	2 599	
CONTINUE TUG THERM. COND. OF SC.	4 3	1 039	2 599	
CONTINUE TUG SUBSYSTEM SUPPT.TO SC	4 4	1 039	2 599	
ACTIVATE SC SUBSYSTEMS MODULES	4 5	008	2 599	
CHECKOUT SC SUBSYSTEMS MODULES	4 7	333	2 607	
ACTIVATE MISSION EQPT. MODULES	4 8	008	2 940	
OPEN SENSOR CONTAMINATION COVERS	4 9	008	2 948	
CHECKOUT MISSION EQPT. MODULES	4 10	333	2 956	
CLOSE SENSOR CONTAMINATION COVERS	4 11	008	3 289	
CHECK DEPLOYABILITY OF APPENDAGES	4 12	050	3 297	
CHECK RF LINKS TO GROUND	4 13	083	3 347	
TAKE FRAME OF ENGINEERING DATA	4 14	033	3 430	
REPORT STATUS TO GROUND	4 15	008	3 463	
DECISION TO RE-SERVICE OR DEPLOY	4 16	167	3 471	
PERFORM UNSCHEDULED SERVICE OPER.	5 0	1 023	3 638	
MONITOR CRITICAL PARAMETERS	5 1	008	3 638	
POSITION CCTV TO OBSERVE SERVICE	5 2	050	3 646	
CONTINUE TUG THERM. COND. OF SC.	5 3	1 023	3 638	
CONFIGURE TUG & SC FOR SERVICE OPS	5 4	050	3 646	
TAKE ENG'NG DATA-SUSPECTED MODULES	5 5	083	3 696	
PROVIDE "ASSISTS" BY MANIPULATOR	5 6	167	3 779	
DEACTIVATE SC MODULES	5 7	008	3 946	
ACTUATE SERVICER, REPLACE MODULES	5 8	333	3 954	
CHECK CONTINUITY OF MODULES	5 9	333	4 037	
ASSIST WITH MANIPULATOR IF NEEDED	5 10	167	4 370	
RECHECK CONTINUITY IF REQUIRED	5 11	083	4 537	
TAKE FRAME OF ENG'NG DATA.	5 12	033	4 620	
REPORT STATUS TO GROUND	5 13	008	4 653	
PREPARE SPACECRAFT FOR DEPLOYMENT	6 0	2 822	5 708	
MONITOR CRITICAL PARAMETERS	6 1	008	5 708	
POSITION CCTV TO OBSERVE DEPLOY.	6 2	050	5 716	
SPIN UP REACTION WHEELS IF REQ'D.	6 3	2 000	5 716	
DEPLOY APPENDAGES AS POSSIBLE	6 4	083	7 716	
SWITCH SC TO INTERNAL POWER	6 5	008	7 799	
DISCONTINUE TUG S/S SUPPORT TO SC	6 6	008	7 807	
CHECK SC RF LINKS TO GROUND	6 7	083	7 815	
DROP TUG-TO-SC UMBILICALS	6 8	017	7 898	
PERFORM PARTIAL CHECK OF SC SYST.	6 9	083	7 915	
PARTIAL CHECK OF MISSION EQUIPMENT	6 10	083	7 998	
SPIN UP SC IF NECESSARY	6 11	050	8 081	
TAKE FRAME OF SC ENG'NG DATA	6 12	033	8 131	
VERIFY SC READY FOR DEPLOYMENT	6 13	333	8 164	
TAKE FRAME OF TUG ENG'NG DATA	6 14	033	8 497	
VERIFY TUG READY FOR DEPLOYMENT	6 15	333	8 164	



3 2.2 9 2 Prepare Spacecraft For Servicing

The Spacecraft is prepared for servicing concurrently with the Tug and many of the descriptions of Tug preparation sub-events in 3 2 2 9 1 apply equally well to the Spacecraft preparations As soon as the umbilicals are connected, the critical parameters of any Spacecraft subsystems which may be operating are monitored by the Tug and despinning, if required, is performed as described previously Thermal conditioning and closed circuit television inspection of the Spacecraft by the Tug are also as described earlier Some variability may exist in the combinations of Spacecraft subsystems which are already active when Spacecraft servicing preparations begin depending on whether the Standard Servicing Module was entered from the Standard Payload Placement Module or from the Standard Docking Module and therefore, different subsystems may require activation Whichever case may apply, the remaining Spacecraft subsystems are activated If required, passivation is completed, and reaction wheels are braked Early in the sequence of events, in fact when critical parameters have been first monitored, checkout of the modules to be replaced begins After all of the modules are activated and checked, a frame of engineering data is taken for reference before any changes are made Having verified the modules to be replaced, the Spacecraft subsystems are deactivated and the modules to be replaced are unlatched At this point the Spacecraft is verified as being ready for servicing and a status report is sent by the Tug to the ground When the Standard Service Module is entered from the Standard Payload Placement Module, all the above events except the unlatching of modules may have been performed in SPPM 6, "Checkout Payload (Spacecraft)" and may be bypassed in SSM 2

3 2 2 9 3 Perform Scheduled Servicing Operations

Critical parameters are monitored during servicing to the extent possible with the Spacecraft subsystems shut down and the closed circuit television is positioned to observe the operation of the Servicer in the module exchange activity The servicer is then activated to exchange the modules previously identified for replacement Some lattitude exists in the module replacement definition to allow for various servicing approaches which may call for manipulators or indexing rack mechanisms The 0 333 hour time allowed for module replacement is compatible with 100% replacement of modules with the "rotating grid" servicer No significant reduction in module exchange time is realized by changing fewer modules down to 50% of the module population Some reduction is possible if fewer than 50% of the modules are exchanged Following replacement of modules, a continuity check is conducted and a report of Spacecraft status is sent to the ground The nominal scheduled servicing operation requires 0 5 hours

3 2 2 9.4 Post-Service Checkout of Spacecraft

Upon completion of scheduled service, the Spacecraft with its complement of new modules is checked out to verify that the malfunctions which required the servicing operation have been cleared This starts with the monitoring of critical parameters to identify any possible jeopardy to the Tug caused by the operation or mere presence of the Spacecraft Identification of such a jeopardy

will cause a decision to jettison the Spacecraft The closed circuit television is positioned in such a way as to allow observation of malfunctions such as leaks, failure of mechanical apparatus such as deployment mechanisms to operate, or signs of fire or explosion Tug subsystem support is required by the Spacecraft for operation, these provisions are verified by the Tug DMS before Spacecraft subsystems are activated for test When the required conditions are met, the Spacecraft subsystems are activated and checked out by the Tug DMS. Mission equipment modules may have sensor contamination covers which are opened and closed as required for the checkout When Spacecraft subsystem and mission equipment modules have been verified, the closed circuit television is positioned in turn to observe each of the retracted appendages such as booms and antennas while the retraction mechanism is operated to the extent possible in the docked condition RF links are established and verified between the Spacecraft and ground, repositioning the Tug if necessary for Spacecraft antenna pointing Finally, a frame of engineering data is taken to make a record of the Tug and Spacecraft status just prior to deployment and a status report is sent to the ground where a decision is made to reservice or deploy the Spacecraft The entire post service checkout operation takes just over one hour to complete

3 2 2 9 5 Perform Unscheduled Service Operations

Following the nominal service mission sequence of events, unscheduled maintenance would be performed if the post service checkout described in 3 3 3 9 4 showed that malfunctions still exist In this case, the monitoring of critical parameters continues throughout the unscheduled service operations When the decision has been made as to what service is to be performed, the closed circuit television is positioned to observe the service operations or any visible effects of them Subsystem support is continued to the Spacecraft and the Tug and Spacecraft are configured for service operations Engineering data is taken to identify, verify, or narrow down the cause of the malfunction and a frame of engineering data is taken on any module which is planned to be replaced Modules to be replaced are deactivated and the Servicer is operated to substitute new modules for suspected ones Continuity checks are made to verify connections on the newly replaced modules During any of these service operations the manipulator is used under television monitoring to give mechanical "assists" if needed. When continuity checks show replacements to be connected correctly, the replaced modules are activated and checkout out by repeating Event SSM 4, "Post Servicing Checkout" When correct operation of the Spacecraft is indicated, a frame of engineering data is taken and the status is reported to the ground If Post Servicing Checkout shows that malfunctions still exist, SSM 5 "Unscheduled Service Operations" can be repeated and the flow of SSM 4 can again be followed to verify proper operation

3 2 2 9 6 Prepare Spacecraft For Deployment

Monitoring of critical parameters continues throughout preparations for deployment and the closed circuit television is positioned to monitor the observable deployment events At this time in the sequence, any required reaction wheel spinup is accomplished The two hour allocation for reaction wheel spinup is bypassed if not required, reducing the time requirement for deployment preparations to less than an hour The television is positioned to observe deployable appendages, one at a time, and these are deployed to the extent compatible with

continued dock to Tug. When Spacecraft checks indicate readiness for deployment, a switch is made to internal power and operation is again checked Thermal and subsystem support is discontinued to the Spacecraft and Spacecraft-to-ground RF links are established Tug-to-Spacecraft umbilicals are dropped and a partial check of Spacecraft subsystems and mission equipment is made by RF link If spin-up is required, it is performed at this time by use of a rotation of the servicer docking mechanism A frame of engineering data is taken and the Spacecraft is verified as being ready for deployment then a frame of Tug engineering data is taken and the Tug is verified as being ready to deploy the Spacecraft At this point, the Standard Service Module exits into Event 9 of the Standard Payload Placement Module which performs the countdown and release Subsequent events in the SPPM command and control the post deployment checkout of the Spacecraft If malfunctions are detected, the Spacecraft can be recovered using the Standard Docking Module functional flow and repairs can be made according to the Standard Service Module flow which follows Event 5 of the Standard Docking Module

3 2 2 10 Orbiter Retrieval

The retrieval of the Tug by the Orbiter is essentially accomplished with the Tug in an attitude hold mode with capture implemented by the Orbiter crew The procedure is the reverse of the deployment sequence with the exception that Tug systems are safed rather than activated at the conclusion of the sequence Figure 3 2 2-10 illustrates the flow of major functions for the retrieval of the Tug from orbit Table 3 2 2-10 lists the events associated with this activity

3 2 2 10 1 Orbiter Acquire Tug Telemetry

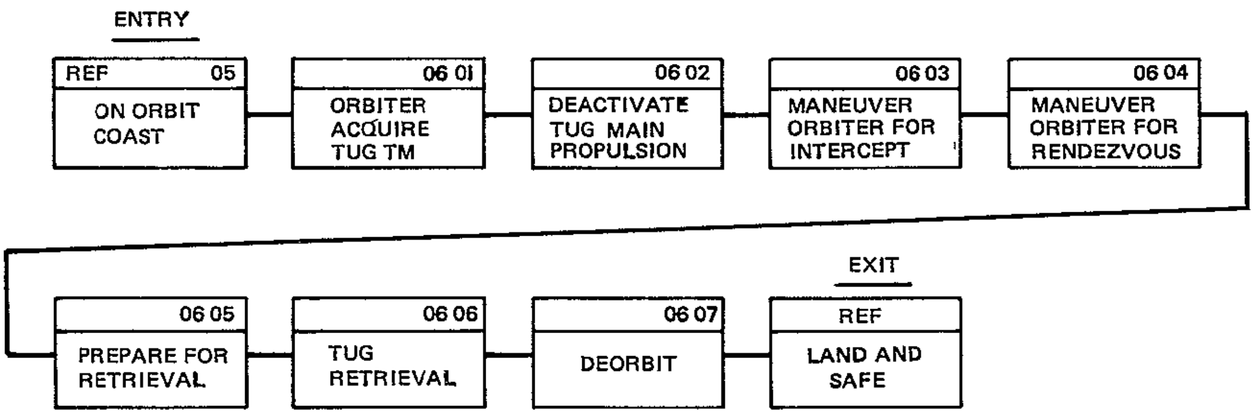
The Tug will enter the Orbiter retrieval mode from the on orbit coast mode where it has been waiting for Orbiter retrieval operations to be initiated The first function of the Orbiter will be to secure RF contact with the Tug to insure continual real time Tug C&W information and Tug command control capability.

3 2 2 10 2 Deactivate Tug Main Propulsion

Prior to deactivation of Tug propulsive systems the TOC and Orbiter crew will concur that the Tug will not be required to make a propulsive maneuver to assist in Orbiter retrieval After this decision, the Tug propulsive system will be safed by dumping both Lox and LH_2 Upon completion of propellant safing the Tug will assume the retrieval attitude and rendezvous aids will be activated The TOC will verify to the Orbiter crew that the Tug and payload are ready for retrieval

3 2.2 10 3 Maneuver Orbiter for Intercept and Rendezvous

The orbital intercept maneuver will be the responsibility of the Orbiter and Orbiter crew The Tug, in a safe condition and in a prescribed attitude will loter in a fixed attitude The TOC will continually monitor Tug status and keep the Orbiter crew informed At the request of the Orbiter crew and with TOC concurrence, command control of the Tug will be transferred from the TOC to the Orbiter crews



STANDARD ORBITER RETRIEVAL MODULE

Figure 3 2.2-10. Standard Orbiter Retrieval Module

3 2.2 10 4 Prepare For Retrieval

The Orbiter will have the option of either flying around or command a Tug attitude change to visually inspect the Tug and payload if desired. The Orbiter will be prepared by the crew for retrieval Included in these activities are opening the Orbiter payload bay doors, assuming the retrieval alignment attitude and activating the RMS and docking adapter The Orbiter crew will receive final concurrence from the TOC that the Tug is ready for retrieval.

3 2 10 5 Tug Retrieval

Tug retrieval begins with the extension of the RMS by the Orbiter crew and the mating of the RMS with the Tug When RMS/Tug mate is accomplished the Tug APS will be automatically deactivated Checks will be conducted at this time to verify the Tug is safe for retrieval. The Orbiter crew will then retract the Tug with the RMS and mate and secure the Tug to the docking adapter (DA) Next the fluid and electrical umbilicals are connected and hard wire communication between Tug and Orbiter verified This being accomplished the Tug RF system will be deactivated and the RMS will be detached and stowed The Tug will then be rotated into the Orbiter bay by the docking adapter and on completion of rotation the forward latches will be secured Forward umbilical connections will be established and when verified secure, Orbiter electrical power will be transferred to the Tug With this complete the crew will safe the Tug fuel cells and configure the Tug and Orbiter bay for re-entry.

3 2 2.10 6 Deorbit

The deorbit sequence will be accomplished by the Orbiter crew with the Tug in a deactivated and safe configuration The only activity by the Tug during this phase will be the maintenance of the Tug safe condition and the caution and warning data from the Tug

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Table 3 2 2-10. Standard Orbiter Retrieval Module

STANDARD ORBITER RETRIEVAL MODULE (06)

Retrieval operations begins with the Space Tug awaiting rendezvous with the Space Shuttle and terminates with the return of the Orbiter to Earth

ENTRY On Orbit Coast
EXIT Post Landing Ground Control

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
ORBITER ACQUIRE TUG TM	01 00	00 167	- 0 267	
ON ORBIT NAVIGATION MODE	01 01			
TUG/ORBITER RF TM LINK ESTABLISHED	01 02	00 167	- 0 267	
DEACTIVATE TUG MAIN PROPULSION	02 00	00 100	- 0 100	
VERIFY TUG PROPULSION SYSTEM NOT NEEDED FOR TUG/ORBITER RENDEZVOUS	02 01	00 017	- 0 067	
COMMAND TUG RETRIEVAL SAFING SEQUENCE (LOX DUMP LH_2 DUMP)	02 02	00 050	- 0 050	
MONITOR AND VERIFY TUG SAFE	02 03	00 050	- 0 050	
COMMAND RETRIEVAL ATTITUDE	02 04	00 017	- 0 033	
VERIFY ATTITUDE AND ATTITUDE HOLD	02 05	00 017	- 0 017	
VERIFY TUG READY FOR RETRIEVAL	02 07	00 017	REF	
MANEUVER ORBITER FOR INTERCEPT	03 00	00 350	Orbiter Functions	
DETERMINE RANGE AND RANGE RATE	03 01	00 067		
DETERMINE INTERCEPT MANEUVERS	03 02	00 033		
COMPUTE TPI BURN PARAMETERS	03 03	00 050		
MANEUVER TO TPI BURN ATTITUDE	03 04	00 133		
PERFORM TPI BURN (OMS ENGINES)	03 05	00 017		
PERFORM COURSE CORRECTION OPS	03 06	00 050		
MANEUVER ORBITER FOR RENDEZVOUS	04 00	00 184		
DETERMINE RANGE AND RANGE RATE	04 01	00 067		
COMPUTE TPF BURN PARAMETERS	04 02	00 050		
ORIENT ORBITER FOR TPF BURN	04 03	00 050		
VERIFY ORBITER READINESS FOR BURNS	04 04	00 050		
PERFORM TPF BURNS (OMS/APS)	04 05			
VERIFY TUG SAFE FOR DOCK	04 06	00 050		
ESTABLISH ORBITER RF TUG COMMAND (ORBITER CONTROL)	04 07			
PREPARE FOR RETRIEVAL	05 00	00 167		
TUG ATTITUDE HOLD MODE	05 01	00 167		
ORBITER INSPECTION OF TUG	05 02	00 067		
ORBITER/TUG RETRIEVAL ALIGNMENT (ORBITER)	05 03	00 100		
PAYLOAD BAY DOORS OPEN	05 04	00 033		
ORBITER CONFIGURED FOR RETRIEVAL	05 05			

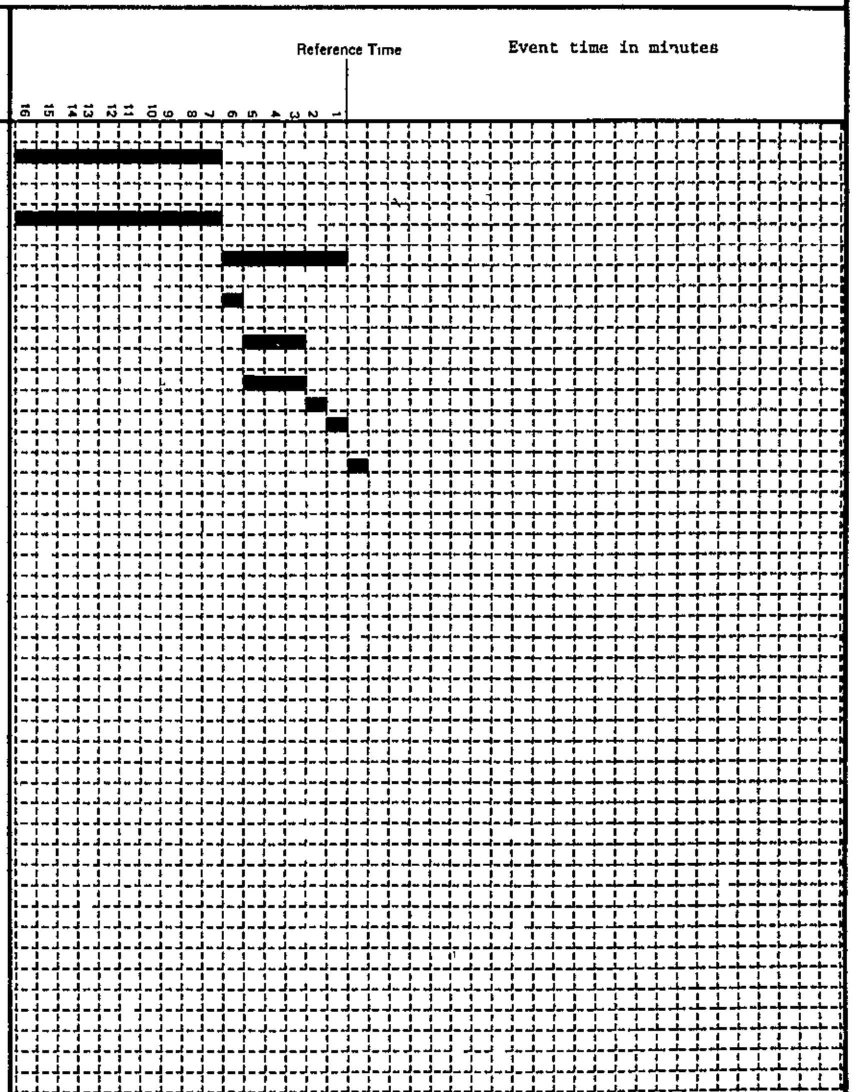
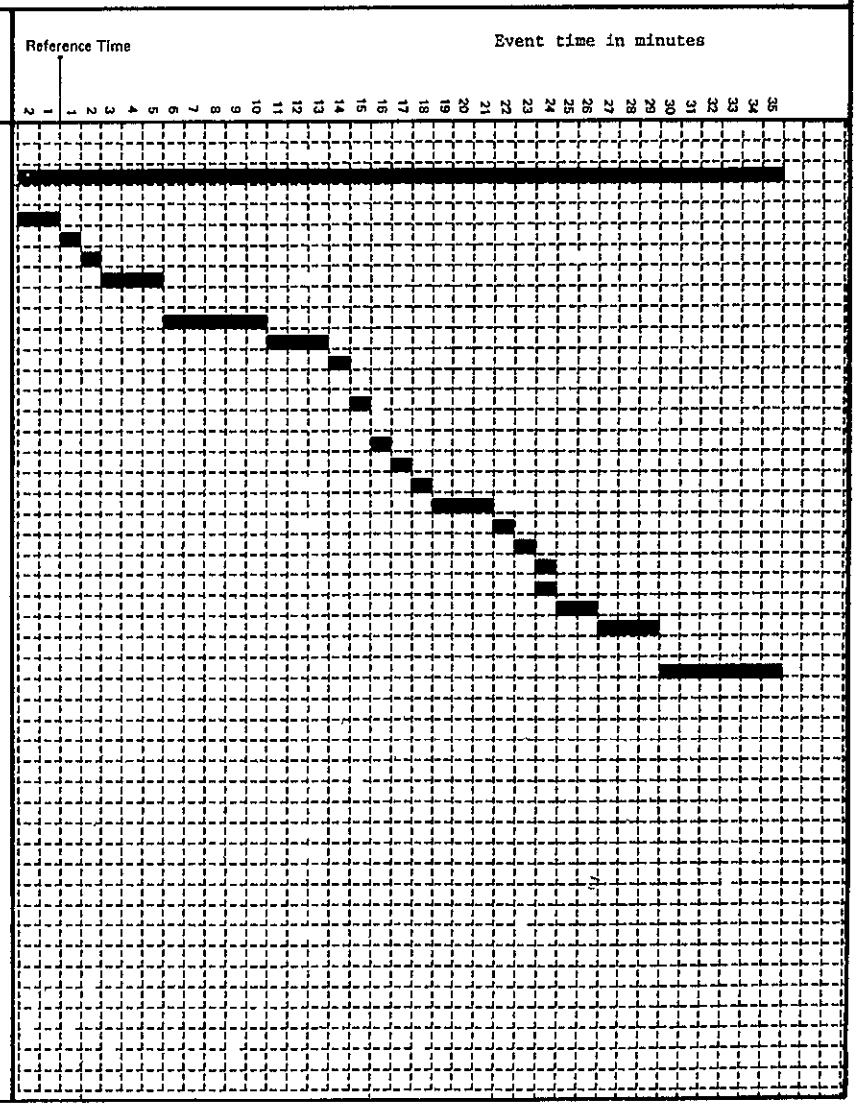


Table 3 2 2-10 Standard Orbiter Retrieval Module (Continued)

STANDARD ORBITER RETRIEVAL (06) (CONTINUED)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
TUG RETRIEVAL	06 00	00 617	- 0 033	
RMS EXTENDED	06 01	00 033	- 0 033	
RMS/TUG MATE	06 02	00 017	REF	
TUG APS DEACTIVATED	06 03	00 017	0 033	
VERIFY TUG CONFIGURED AND SAFE FOR RETRIEVAL	06 04	00 050	0 050	
TUG RETRACTION BY RMS	06 05	00 083	0 100	
TUG/DA MATE	06 06	00 050	0 167	
DA FLUID AND ELECTRICAL CONNECTIONS ESTABLISHED	06 07	00 017	0 233	
TUG/ORBITER HARDWIRE COMMUNICATION VERIFIED	06 08	00 017	0 250	
TUG RF OFF	06 09	00 017	0 267	
RMS DETACHED AND STORED	06 10	00 017	0 283	
TUG CONFIGURED FOR DA ROTATION	06 11	00 017	0 300	
TUG ROTATED INTO ORBITER BAY	06 12	00 050	0 317	
FORWARD LATCHES ENGAGED	06 13	00 017	0 367	
UMBILICALS CONNECTED	06 14	00 017	0 383	
ELECTRICAL POWER TRANSFER	06 15	00 017	0 400	
TUG FUEL CELLS OFF	06 16	00 017	0 400	
PAYLOAD BAY DOORS CLOSED	06 17	00 033	0 417	
TUG SYSTEMS CONFIGURED FOR RE-ENTRY	06 18	00 050	0 450	
PAYLOAD BAY CONFIGURED FOR RE-ENTRY	06 19	00 100	0 500	
DEORBIT	07 00	Orbiter Functions		
PERFORM DEORBIT COAST OPERATIONS	07 01			
PERFORM DEORBIT MANEUVERS	07 02			
PERFORM ENTRY AND DESCENT MANEUVERS	07 03			
PERFORM APPROACH AND LANDING	07 04			



In deriving a specific abort timeline for a mission, the time of abort is compared to the time brackets noted for each abort mode, enabling selection of the applicable abort mode This mode is followed through the logic paths of the overall functional flow thus identifying those major events which apply and their timing sequences. The abort time within the mission is then taken as the reference time for the beginning of the major event sequence Times within the mission for each applicable major event and its sub-events are then calculated by adding times within the module to the mission time at which abort is initiated Finally the appropriate numerical prefixes are added to the event and sub-event numbers to fix the Abort Module in the overall sequence of modules for the mission of interest.

3 2 2 11 Abort Module

The Shuttle System provides intact abort capability throughout all mission phases Definition of the Orbiter/External Tank abort modes has been simplified by the assumption that a failure of Tug/SC will not necessitate an Orbiter/ET abort This assumption is validated by the Tug/SC design requirement which prevents any single failure of Tug or Spacecraft from injuring flight personnel or damaging the Orbiter or other payloads This, in combination with the specified capability of the Orbiter to dump hazardous fluids and pressurants overboard within the time constraints imposed by an abort situation, relieves the Shuttle System of urgency in responding to Tug/SC abort requirements Nevertheless, the sequence of events in a Tug/SC flight abort timeline is strongly influenced by the functional status of the Shuttle System elements when the need for a Tug/SC abort is identifed Except for pre-launch aborts, which are not covered in this study, all possible combinations of Shuttle System element status are covered by only four abort modes

- Return to Launch Site (RTLS)
- Abort Once Around (AOA)
- Abort to Orbit (ATO)
- Abort From Orbit (AFO)

Since all of the flight abort modes have commonality in functional requirements, some of the major functions and events can be shared. Therefore, a single functional flow has been structured for the Standard Abort Module which can be entered and exited in such a way that all four abort modes can be accomplished by various combinations of its seven major functions and events These are distinguished in Figure 3 2.2-11 by the darkened outlines. Boxes with the lighter outlines in the Standard Abort Module functional flow illustrate points of entry and exit and references to interfaces with other standard timeline modules. Notice that the rendezvous and retrieval functions of the Standard Retrieval Module form a part of Standard Abort Module functional flow for the Abort From Orbit mode

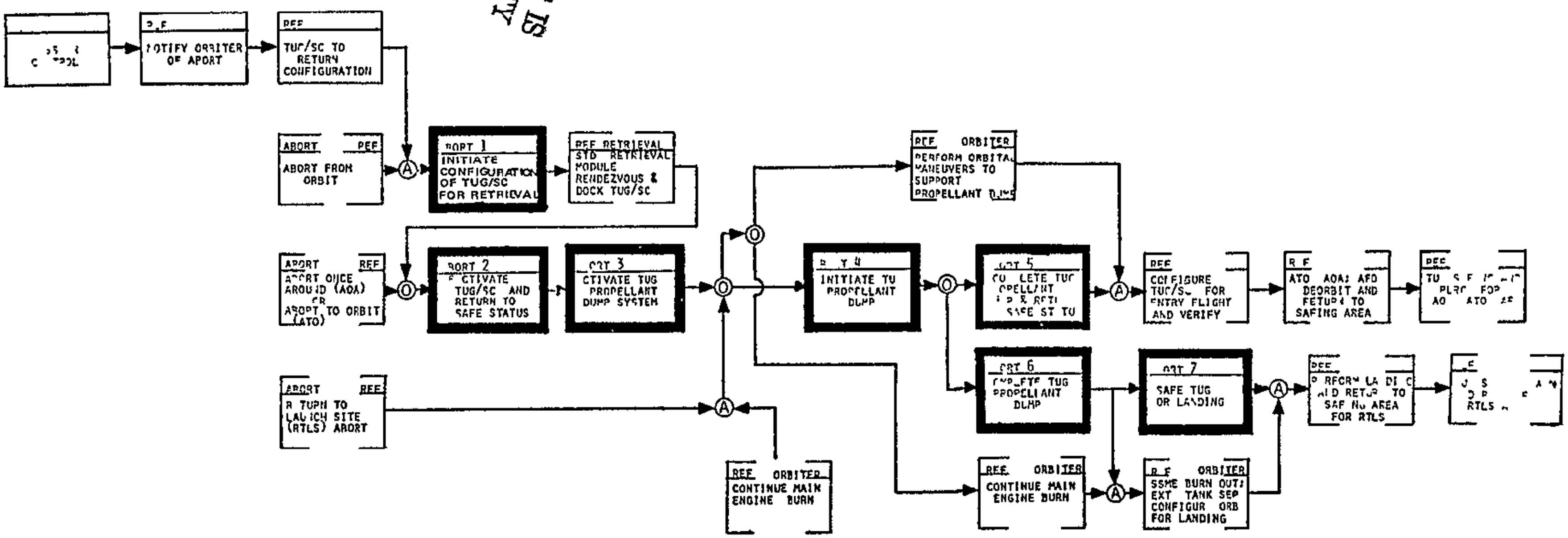


Figure 3.2.2-11. Standard Abort Module

The seven major events are further defined in Table 3 2 2-11 with event number, sub-event descriptions, time duration, and start time within the module Relative timing relationships between events and sub-events is illustrated in bar chart form Notes on the bar chart show times within the mission sequence when each of the four abort modes applies

3 2 2 11 1 Initiate Configuration of Tug/SC For Retrieval

A Tug/SC abort initiated any time after separation from the Orbiter necessitates rendezvous and docking before the sequences shared by the other abort modes can begin This required rendezvous and docking sequence has been defined in the Standard Orbiter Retrieval Module for the operational retrieval and deorbit of the Tug/SC and is therefore used as shown in Figure 3 2 2-11 for the second major functional sequence in the Abort From Orbit mode Since the entry point to the Standard Orbiter Retrieval Module is "Orbiter Acquire Tug TM", the abort functions occuring between identification of the abort requirement and Orbiter acquisition of Tug TM are defined in "Initiate Configuration of Tug/SC for Retrieval", which is labeled "Event 1.0" in the Standard Abort Module. When the need for Tug/SC abort is identified, the Tug is commanded (sub-event 1 01, Table 3 2.2-11) to monitor and transmit subsystem status data to the ground or to the Orbiter if it is in the vicinity Next, the Tug is commanded by the Orbiter or ground as applicable to assume and hold an attitude suitable for thermal and communications purposes, while awaiting the rendezvous and retrieval functions When attitude stability has been achieved, non-essential subsystems and equipment are shut down by command from the Orbiter or ground as applicable and critical parameters are monitored until conditions permit the retrieval operation to begin as defined in Section 3 2 2 10, "Orbiter Retrieval", continuing up to the point of Tug/SC deactivation and safing, the entry point for the second major event (Abort 2) of the Standard Abort Module

3 2 2 11 2 Deactivate Tug/SC And Return To Safe Status

Once the Tug/SC is aboard the Orbiter, the Abort From Orbit sequence can follow the same functional path as the Abort Once Around or Abort to Orbit modes, "Deactivate Tug/SC and Return to Safe Status" which is major event two in the Standard Abort Module When abort is initiated any time in the range of 259 to 373 seconds after launch, the Abort Once Around mode is used Between the times of 373 and 532 seconds, the status of the Orbiter and Ground is such that the Abort to Orbit mode is better suited to the circumstances Whichever of the 3 modes (AFO, AOA, or ATO) is being followed, the first sub-event is monitoring of caution and warning If Tug/SC activation and checkout is in process at the time a decision to abort is reached, this activity is terminated Next, the Data Management System (DMS) aboard the Tug sequences the passivation of all other subsystems (except any needed for propellant dumping) and sends status reports to Orbiter and Ground as applicable This event exits into event (Abort 3)

3 2.2.11 3 Activate Tug Propellant Dump System

This event which is common to the AFO, AOA, and ATO abort modes begins with the continued monitoring of caution and warning and critical parameters Fluid system venting is switched from zero g to positive g venting and while monitoring

Table 3 2.2-11 Standard Abort Module

STANDARD ABORT MODULE	
The Abort Module defines the sequence of Tug events for the mission periods of potential orbiter abort	ENTRY Aborts, return to launch site, abort once around, abort to orbit, abort from orbit, pad abort EXIT Orbiter landing and two to safing area for AOA, ATO AFO perform landing for RTLS, backout/payload changeout for pad abort

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
VERIFY TUG/SC SAFE FOR RETRIEVAL	01 00	217	000	
ESTABLISH TUG-ORBITER RF COMMUN	01 01	050	000	
TRANSFER TUG CONTROL TO ORBITER	01 02	033	050	
MAINTAIN COMMANDED ORIENT. & ATT	01 03	138	083	
TUG DMS VERIFY STATUS OF TUG/SC	01 04	083	083	
DEACTIVATE TRANSPONDER (ORB CMND)	01 05	008	083	
SAFE ALL SUBSYST EXCEPT ACS &CMND	01 06	100	100	
SHUTDOWN/SAFE ACPS(ORBITER COMMAND	01 07	017	200	
DEACTIVATE TUG/SC & RETURN TO SAFE STATUS	02 00	191	090	
MONITOR CRITICAL PARAMETERS	02 01	191	090	
TERMINATE ACTIVATION & C/O (CMND)	02 02	008	100	
DMS SEQUENCE SUBSYSTEM PASSIVATION	02 03	167	108	
SEND TUG/SC STATUS TO ORBITER/GND	02 04	033	250	
ACTIVATE TUG PROPELLANT DUMP SYST	03 00	058	117	
MONITOR CRITICAL PARAMETERS	03 01	058	117	
TRANSFER PROPELLANT TANK VENT	03 02	017	117	
CONFIGURE DUMP/DRAIN LINES	03 03	033	117	
INITIATE PROP TANK PRESSURIZATION	03 04	008	50	
MONITOR/TRANSMIT TUG/SC STATUS	03 05	017	158	
INITIATE TUG PROPELLANT DUMP	04 00	083	167	
MONITOR CRITICAL PARAMETERS	04 01	083	167	
RECEIVE DUMP INITIATE COMMAND	04 02	008	167	
PRESSURIZE LO_2 AND LH_2 PROP TANKS	04 03	017	175	
DMS SEQUENCE TRICKLE TO FULL FLOW	04 04	038	183	
DMS MONITOR DUMP PROCESS REPORT	04 05	075	167	
MAINTAIN PROG. ATT. & ORIENTATION	04 06	083	167	
SEND TUG/SC STATUS TO ORBITER/GND	04 07	017	233	
COMPLETE TUG PROPELLANT DUMP AND RETURN TO SAFE STATUS	05 00	158	175	
MONITOR CRITICAL PARAMETERS	05 01	158	175	
DMS SEQUENCE SAFE END OF DUMP	05 02	008	175	
TERMINATE TANK PRESSURIZATION	05 03	008	175	
REINITIATE HELIUM PURGE	05 04	150	183	
DMS CONFIGURE PROPULSION FOR LAND	05 05	033	190	
DMS VERIFY DUMP COMPLETE	05 06	033	225	
DMS SEQUENCE TUG/SC TO SAFE COND	05 07	050	260	
SEND TUG/SC STATUS TO ORBITER/GND	05 08	025	310	

Time scale: 017 033 050 067 083 100 117 133 .150 167 183 200 217 233 250 267 .283 300 317 333 350 367 383 400 417 433 450 467 483 500

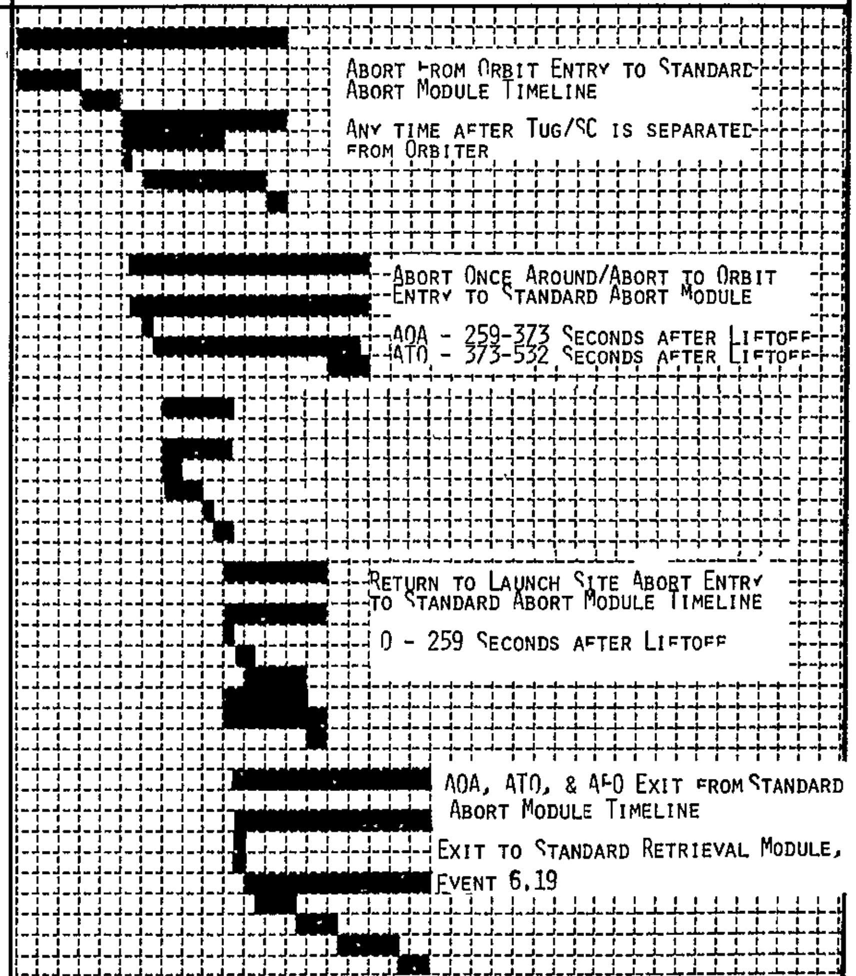
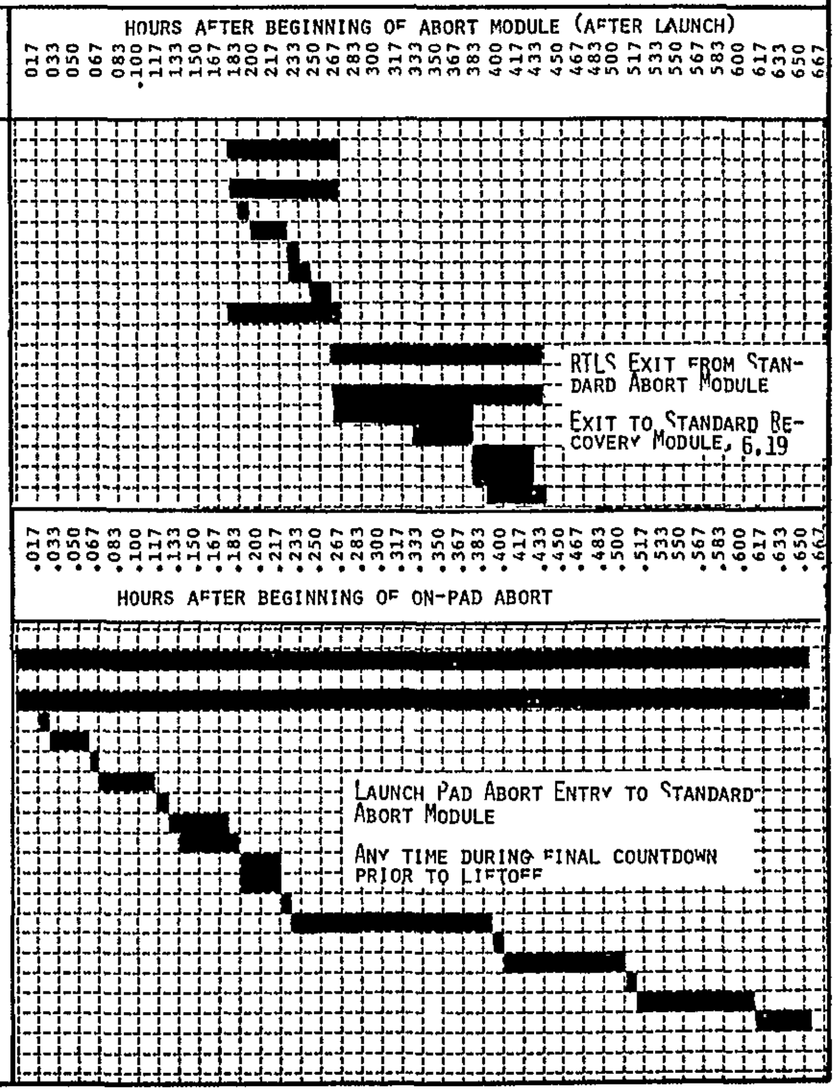


Table 3.2.2-11. Standard Abort Module (Continued)

STANDARD ABORT MODULE (PAGE 2 CONTINUED)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (HOURS)	EVENT START TIME IN MODULE (HOURS)	EVENT START TIME IN MISSION (HOURS)
COMPLETE TUG PROPELLANT DUMP	06 00	092	175	
MONITOR C&W REPORT TO ORBITER/GND	06 01	092	.175	
DETECT PROPELLANT DEPLETION	06 02	008	183	
DMS SEQUENCE SAFE SHUTDOWN OF DUMP	06 03	033	190	
STOP LO_2&LH_2 Abort Pressurization	06 04	008	225	
CLOSE DRAIN/DUMP LINE	06 05	017	225	
OPEN POSITIVE G VENT	.06.06	.017	240	
MONITOR DUMP REPORT STATUS-ORB/GND	06 07	092	175	
SAFE TUG FOR LANDING	07.00	175	260	
MONITOR C&W REPORT TO ORBITER/GND	07.01	.175	.260	
DMS SEQUENCE PROP SYST INERT	07 02	117	260	
DMS SEQUENCE PRESSURIZATION DOWN	07 03	.050	.325	
MAINTAIN HELIUM PURGE-LO_2 & LH_2	07 04	050	375	
MAINTAIN LO_2&LH_2 Tank HE Pressurization	07 05	050	375	
MONITOR STATUS REPORT TO ORB /GND	.07 06	050	.385	
LAUNCH PAD ABORT	08 00	658	000	
MONITOR C&W REPORT TO ORBITER/GND	08 01	658	000	
ESTAB SAFE HOLD VERIFY CONTINUE	08 02	008	017	
TERMINATE PROP LOADING/TOPPING	08 03	033	025	
ESTAB SAFE HOLD VERIFY CONTINUE	08 04	008	060	
RETURN TUG TO SAFE STATUS	.08 05	050	067	
ESTAB SAFE HOLD VERIFY CONTINUE	08 06	008	117	
ACCOMPLISH LH_2 DUMP	08 07	050	125	
ACCOMPLISH LO_2 DUMP	08 08	050	133	
ACCOMPLISH ACPS DUMP	08 09	033	183	
DUMP FUEL CELL REACTANTS	08 10	033	183	
ESTAB SAFE HOLD VERIFY CONTINUE	08 11	008	225	
PURGE PROPELLANT SYSTEMS	.08 12	166	225	
ESTAB SAFE HOLD VERIFY CONTINUE	08 13	008	390	
VENT AND SAFE PRESSURIZATION SYST	08 14	100	400	
ESTAB SAFE HOLD VERIFY CONTINUE	08 15	008	517	
SECURE ALL SYSTEMS IN SAFE CONDIT	08 16	100	525	
MONITOR STATUS REPORT TO ORB /GND	08 17	050	.625	



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the propellant system status through the data link, the Orbiter OMS or RCS engines are fired to settle Tug propellants in tanks When propellants are settled, the abort pressurization system pressurizes propellant tanks as sequenced by DMS Tug status is monitored continuously and relayed to ground stations

3 2 2 11 4 Initiate Tug Propellant Dump

This event (Abort 4) is common to all four abort modes It begins with caution and warning, and critical parameter monitoring when implementing the RTLS abort mode or continues such monitoring which was already begun for the AFO, AOA, and ATO abort modes When propellant tank pressurization is complete, the DMS sequences beginning of dumping by first controlling flow to a trickle, chilling down lines, then increasing flow to a full flow condition When full flow is reached, the OMS or RCS thrusting begun earlier for the AFO, AOA, ATO abort modes is terminated completing dumping by blowdown Since the Orbiter engines are still operating at time of RTLS abort, the forward thrust supports dumping During the dumping operation the DMS monitors-Tug status which is provided to the Orbiter for relay to the ground stations

3.2.2 11 5 Complete Tug Propellant Dump And Return To Safe Status

This event (Abort 5), which applies only to the AFO, AOA, and ATO abort modes, continues the monitoring of caution and warning, and critical parameters. When sensors detect propellant depletion in LH_2 and LO_2 tanks, the DMS sequences the shutdown of tank pressurization, the closing of drain and dump lines, and the beginning of helium purge for entry and landing. Throughout this event the DMS continues to monitor Tug status which is provided to the Orbiter for relay to the ground This event exits into event 7 of the Standard Orbiter Retrieval Module, "Deorbit".

3 2 2 11 6 Complete Tug Propellant Dump

This event applies only to the RTLS abort mode and takes advantage of the inpulse provided by the continuing main engine burn to complete propellant dumping Monitoring of caution and warning, and critical parameters continues, and specifically, tank sensors detect propellant depletion. When depletion is indicated, the DMS sequences the halting of the dump process by stopping LO_2 and LH_2 abort pressurization, closing drain/dump lines, and opening the positive g vent A backup program in the Orbiter DMS acts as a backup to sequence the termination of the dump operation safely. Instrumentation and the DMS monitor vehicle status which is provided to the Orbiter for relay to the ground

3 2 11 7 Safe Tug for Landing

This event, which applies only to the RTLS abort mode continues the monitoring of caution, warning, and critical parameters The DMS sequences safing of the LO_2 and LH_2 propellant system and the abort pressurization system and controls

the LO_2 and LH_2 helium purge to the transport pressure. Instrumentation and the DMS monitor vehicle status which is provided to the Orbiter for relay to the ground This event exists into Event 7 of the Standard Orbiter Retrieval Module, "Deorbit".

SPACE TUG CONFIGURATION DESCRIPTION 4

A baseline Space Tug configuration was provided by NASA/MSFC as a basis for the operational and costing analyses required in the study effort. This section gives an overview of the subsystems and operational configurations for the Space Tug The baseline configuration was derived from the information included in References No 1 and No 16.

4 1 OVERALL TUG DESCRIPTION

The Space Tug is 30 feet long and 14 2/3 feet in diameter and consists of LH_2 tank, a LO_2 tank, a RL-10 derivative IIB main engine with an extendable nozzle, and a body shell made up of a forward skirt, main skirt and aft adapter The basis Tug configuration is shown in Figure 4.1 0-1 The Tug includes a hydraulic system for activator control, a termal control system, a helium bottle system for purging, pressurization and valve control, an auxiliary propulsion system, and an avionics system The avionics include the following subsystems

- Data Management
- Guidance, Navigation and Control
- Rendezvous and Docking
- Electrical Power and Distribution
- Communications
- Measurement

The Tug (and deployment adapter) wet weight is approximately 58,600 pounds with a Tug dry weight of approximately 5100 pounds

4 2 STRUCTURAL SUBSYSTEM

The following is a summary of the structural elements of the Tug and their basic function

- Forward Skirt - supports the payload, docking mechanism, non-propulsive vent system, and a portion of the avionics The forward Tug/Spacecraft structural support attachment allows the deployment and retrieval of Spacecraft
- Main Skirt - supports the LO_2 and LH_2 tanks, four APS thruster packages, 3 hydrazine tanks, helium bottles, selected avionics including the fuel cells, and various umbilicals, panels and platforms.
- LH_2 and LO_2 Tanks - provide the storage for Space Tug propellants.
- LH_2 and LO_2 Tank Supports - provide structural support for the LH_2 and LO_2 tanks

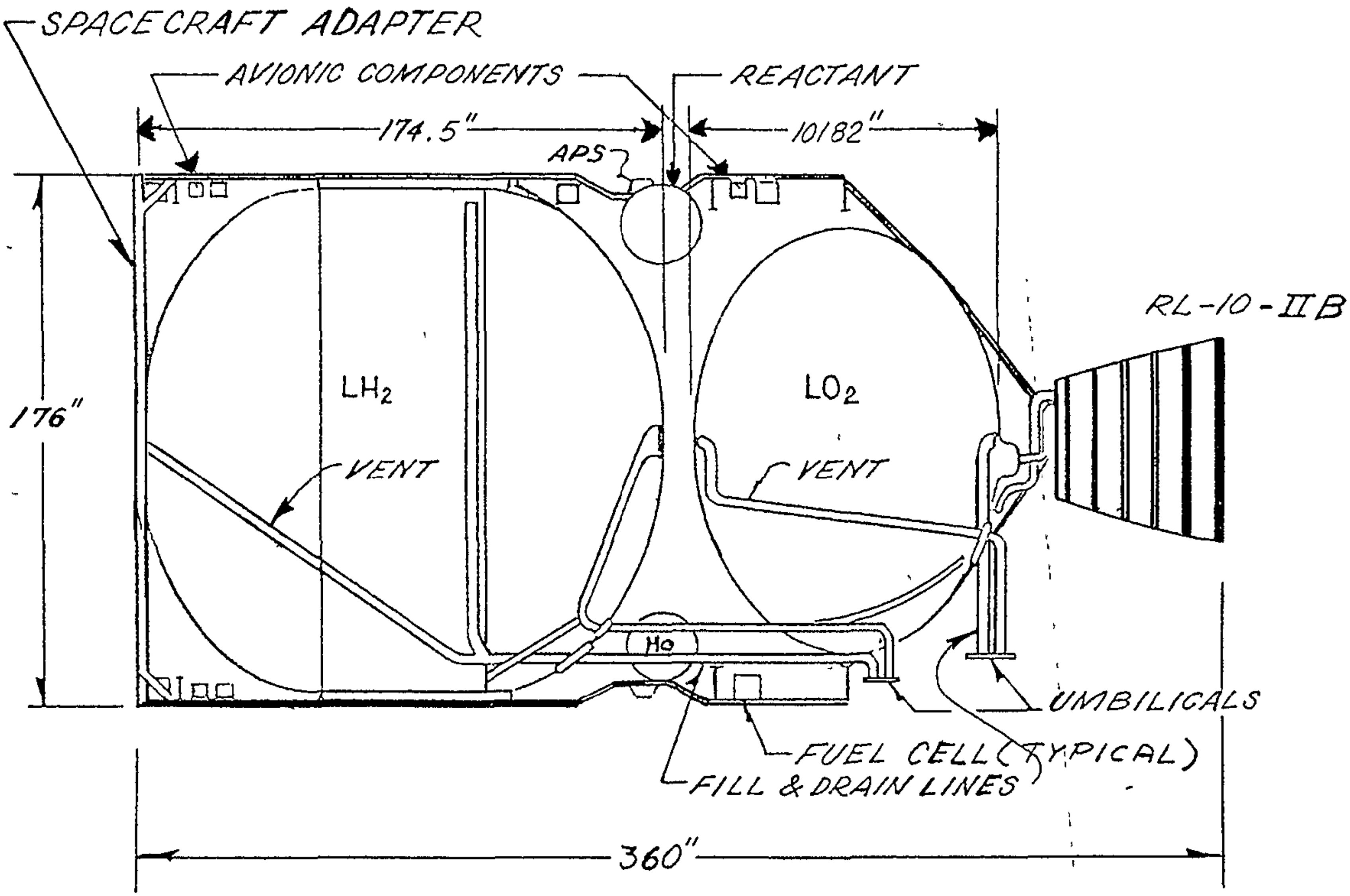

Figure 4 1.0-1. Space Tug Basic Configuration

- Thrust Structure - provides engine interface structure

- Thermal Insulation - provides thermal protection and micrometeriod protection

- Deployment Adapter - provides Orbiter interface structure including Tug latching system, umbilical plates, and propellant drain and dump The adapter is used to pivot and rotate the Tug from the Orbiter payload bay during deployment

- Tug/Orbiter Umbilicals - provides vent and propellant lines, the purge and electrical interfaces connections between Tug and Orbiter

4 3 PROPULSION AND MECHANICAL SUBSYSTEMS

The following is a summary of the propulsion and mechanical subsystem components and pertinent operational characteristics baselined for the Space Tug vehicle

4 3 1 Main Engine

The baseline engine is the Pratt and Whitney RL-10 Derivation IIB with thrust levels of 15,000 lbs, for major ΔV maneuvers and 3,750 lbs for small ΔV maneuvers A retractable nozzle is extended after Orbiter deployment and retracted prior to recovery by electric motor driven screw jacks Normally closed prevalves are present in both the fuel and oxidizer lines to prevent propellant from reaching the engine until it is desired The engine requires application of pneumatic and electrical power and a start signal to initiate its start sequence The engine is stopped by removal of the start signal and rendered safe by removal of penumatic and electrical power. Five failures (two valves, pneumatic and electric power application and start signal) would be required to inadvertently fire the engine

4 3 2 Propellant and Pressurization

The propellant feed, fill and drain system configuration is shown in Figure 4 3 2-1 The propellant feed system consists of the valves and ducting between the propellant tanks and the engine pump inlets The propellant fill, drain and dump consists of the valves and ducting the Tug/Orbiter/ external interfaces and the propellant tanks The LH_2 feed line doubles as the fill and drain system Prevalves are located in the LH_2 feedlines to isolate the propellant tanks from the engine and to act as redundant feed system valves in combination with the engine inlet valves The LO_2 fill system contains dual fill and drain valves to provide redundancy for critical dump operations during a launch abort No redundancy is provided for any system beyond the "fail safe" mode

The pressurization system provides tank pressurant for main engine requirements and for engine pneumatic requirements The system schematic is shown in Figure 4 3 2-2 Helium is used for tanks pressurization and mainstage pressurization is provided by GH_2 and GO_2 tapoffs on the main engine Redundancy is provided in the regulation of both the LO_2 pressurization and the pneumatic system Two regulators in parallel protect against the failed closed regulator mode, a shutoff valve in each leg protects against the failed

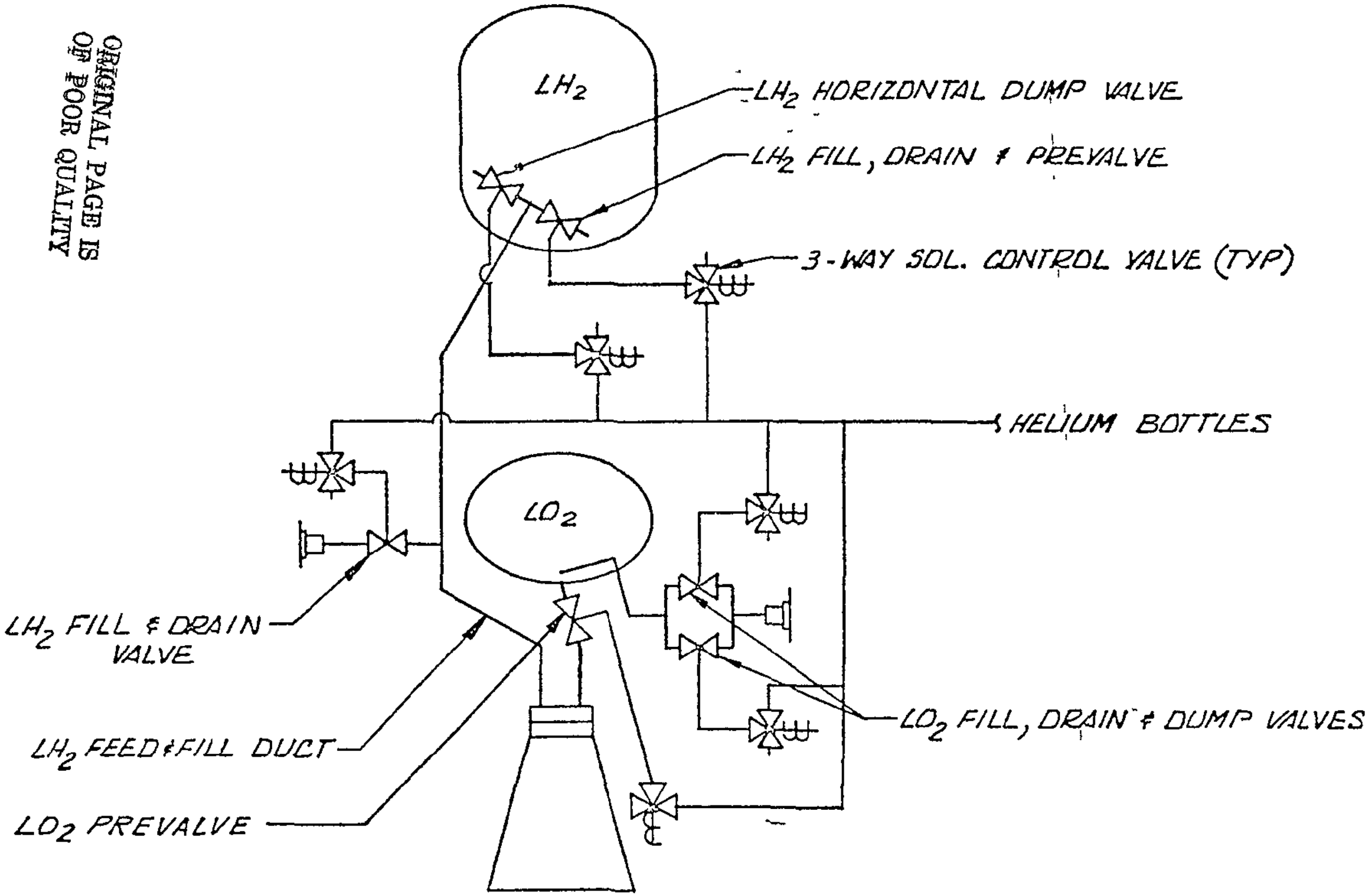

Figure 4.3.2-1 Space Tug Propellant Feed, Fill and Drain System

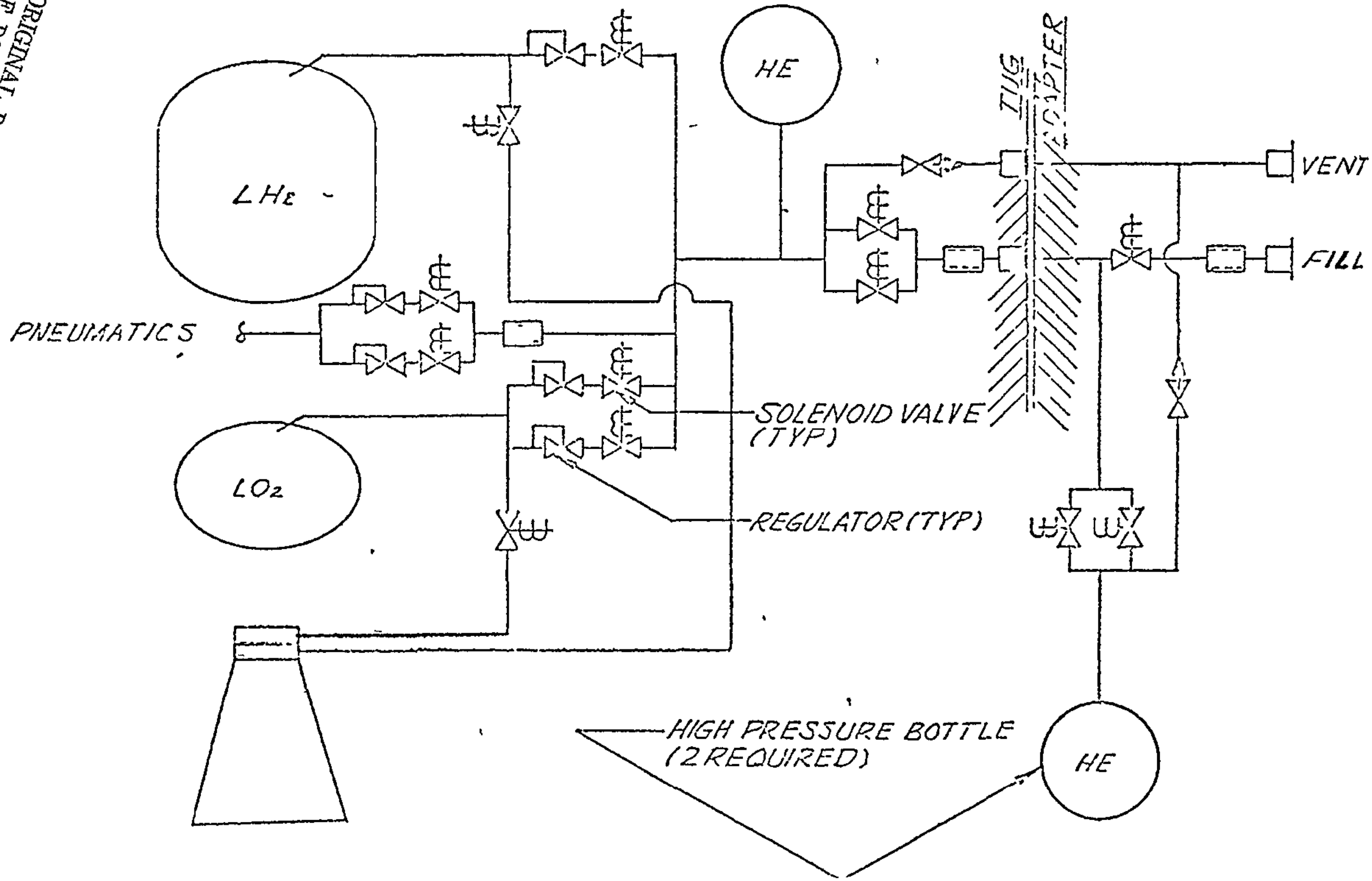

Figure 4 3.2-2 Space Tug Pressurization/Pneumatic System

open mode, and relief valves in series protect against system over-pressurization or loss of helium due to leakage Control of GH_2 and GO_2 flow from the main engine tapoff will be by single non-redundant solenoid valves

The vent system provides the control devices for tank venting during propellant loading and to prevent tank over-pressurization The system schematic is shown in Figure 4 3 2-3 The primary vent systems are functional during loading, ascent and positive acceleration periods The secondary tank vent system vents the LH_2 and LO_2 tanks during periods of zero or low acceleration Redundnacy in both the LO_2 and LH_2 systems is provided through the use of dual valving Each vent valve has its own pneumatic control valve so that valve interdependence is eliminated

The propellant loading and monitoring system, shown in Figure 4 3 2-4, provides propellant mass indications during loading and powered flight Propellant mass signals are supplied to the Tug telemetry system for continuous monitoring of propellant masses during burns or propellant setting maneuvers During coast periods, mass readings are not a true indication of the propellants onboard Low level point sensors are included in each tank to provide engine cutoff to protect the propulsion system against a depletion shutdown

4 3 3 Hydraulics

The hydraulic system provides vehicle attitude control in pitch and yaw during mainstage operation by directing the main engine thrust vector It is a closed loop system, receiving commands from the Tug onboard computer, to provide the required gimballing control signals Several components are employed to provide performance information

- A flight control feedback transducer monitors actuator movement and transmits the closed-loop feedback (error) signals
- A position switch indicates a preset reservoir fluid volume level
- A thermal switch, mounted on the main pump manifold, shuts off the auxiliary pump when return fluid temperature exceeds a preset level
- A temperature transducer monitors a return fluid temperature.
- Low and high pressure transducers monitor return fluid and operating fluid pressures for performance records
- A differential transducer, coupled to each actuator assembly, monitors the difference in pressure between each side of the actuator for performance records.

4 3 4 Auxiliary Propulsion System (APS)

The auxiliary propulsion system is shown schematically in Figure 4 3 4-1 The APS provides for three axis attitude control and translation capability by using four clusters of six thrusters located at 90° intervals around the stage Each thruster produces 25 lbs thrust Normally-open isolation valves are located at the inlet to each cluster of thrusters and each thruster is equipped with series redundant propellant valves The APS design also includes relief and vent valves to protect against tank over pressurization

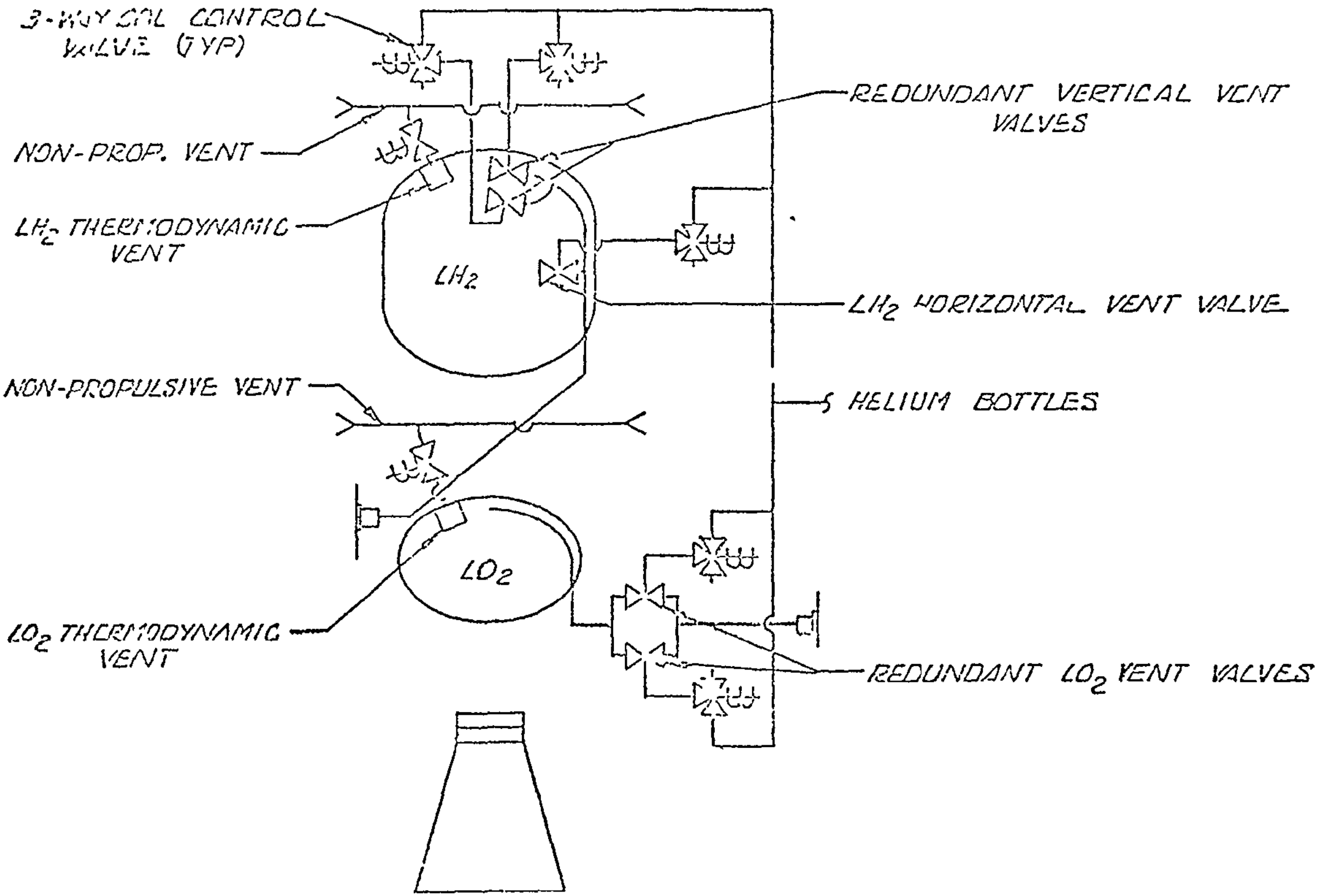

Figure 4.3.2-3 Space Tug Vent/Relief System

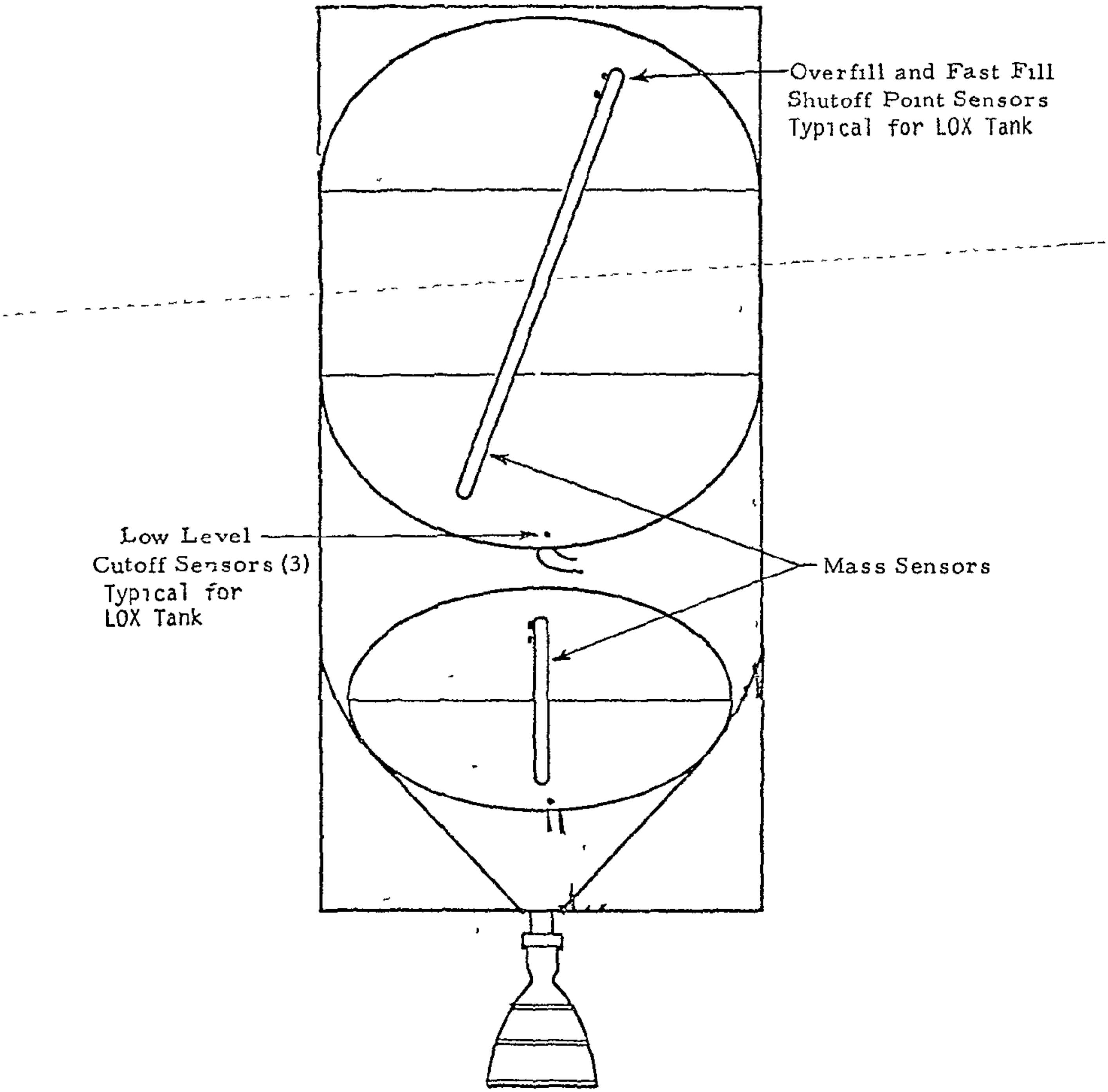

Figure 4 3.2-4. Space Tug Propellant Loading and Monitoring System

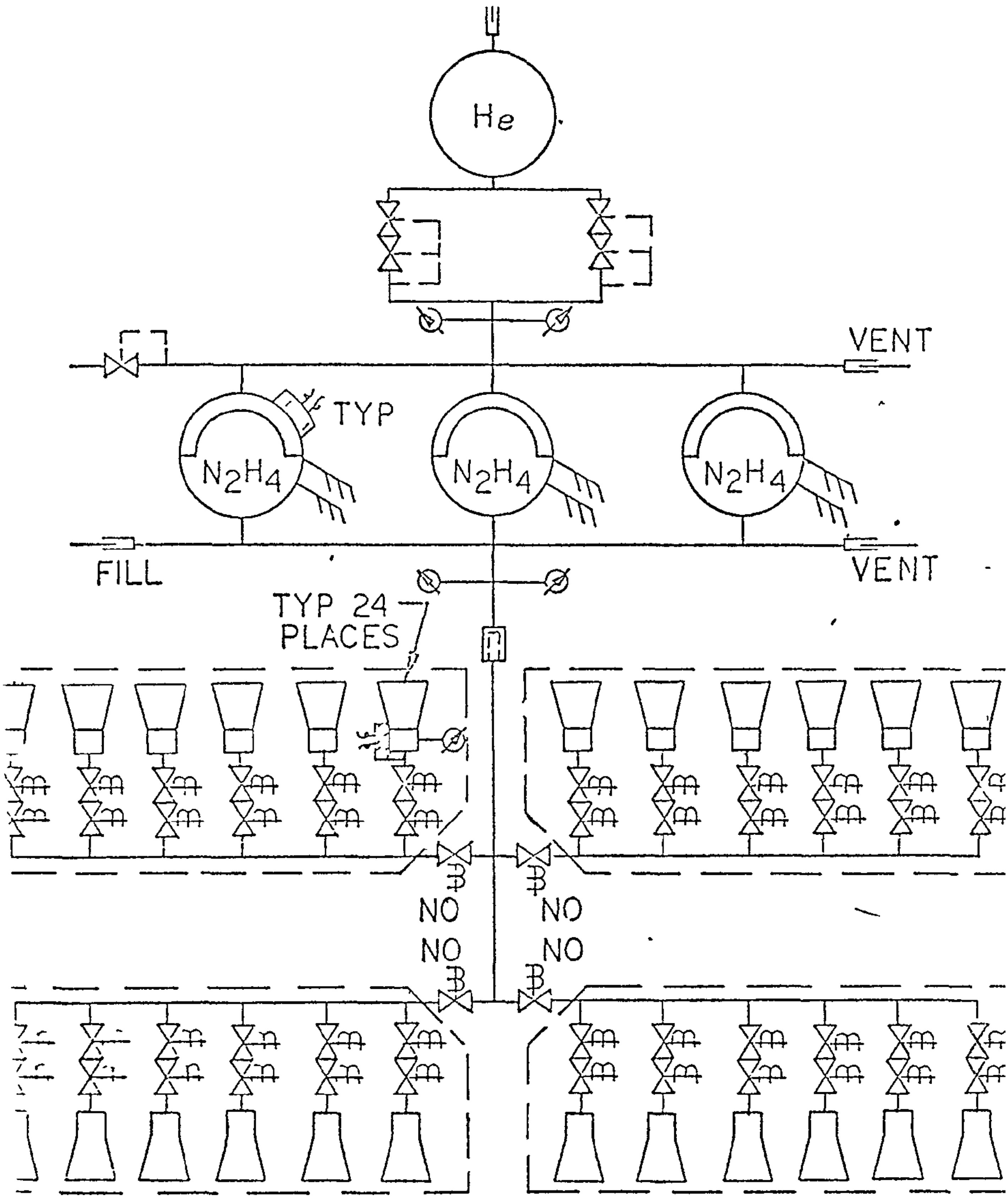

Figure 4 3.4-1. Space Tug Integrated Hydrazine APS

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4 3 5 Thermal Conditioning System

Space Tug avionics thermal control is provided in the forward skirt by radiation shields, heaters and heat pipes, while the intertank electronics require only heat pipes for temperature stabilization

The fuel cells use an active thermal conditioning system shown schematically in Figure 4 3 5-1 for heat dissipation It should be noted that the use of the new technology lightweight fuel cells could reduce the heat dissipation requirements The system uses a coolant circulated by redundant pumps through space radiators, selector valves, a temperature mixing valve, and a fuel cell heat exchanger Dual redundant modulating flow control valves regulate the amount of coolant flowing through the radiator. The accumulator is pressurized with helium through a normally-open solenoid valve and pressure regulator A relief valve is provided to prevent excessive pressure buildup in the accumulator

4 4 AVIONICS SUBSYSTEM

Ther baseline avionics system used for the study was derived mainly from the December, 1974, GDC Avionics presentation (Reference No 1) The avionics are divided into five major subsystems as shown in Figure 4 4 0-1 Two autonomy levels were included in the costing exercise, but the only avionic difference was an increase in software for onboard targeting for Level II autonomy.

4 4 1 Avionics Overview

A system block diagram of the proposed baseline Space Tug avionics is shown in Figure 4 4 1-1 and its associated equipment list, including weight, power and volume summaries are shown in Table 4 4.1-1 A typical installation layout of the Tug avionics is shown in Figure 4 4 1-2 Basically, the system includes a central computer with data bus and terminals for data acquisition, distribution and onboard processing The Tug interfaces with the GSE, Orbiter and Spacecraft Guidance and navigation sensors provide for attitude reference navigation and attitude update capability. Communications capability allows RF interface with the Orbiter and ground, while the rendezvous and docking elements allow the capability for the retrieval of Spacecraft Fuel cells provide the basic power generation capability for the Tug

The redundancy for Tug subsystems is shown in Table 4 4 1-2 This table also includes the function of each subsystem and the components or subsystems critical to mission success

The following sections include a brief summary of the avionic subsystems and their flight operations related characteristics

4 4 2 Data Management Subsystem

The data management subsystem of the Tug is the major integrating element of the avionics, controlling the data processing and data control for all Tug avionic subsystems The major components of the DMS can be seen in Figure 4 4 0-1 and 4 4 1-1 The DMS is a dual redundant system consisting of fault tolerant memory modules with a translator, central processor units (CPU's),

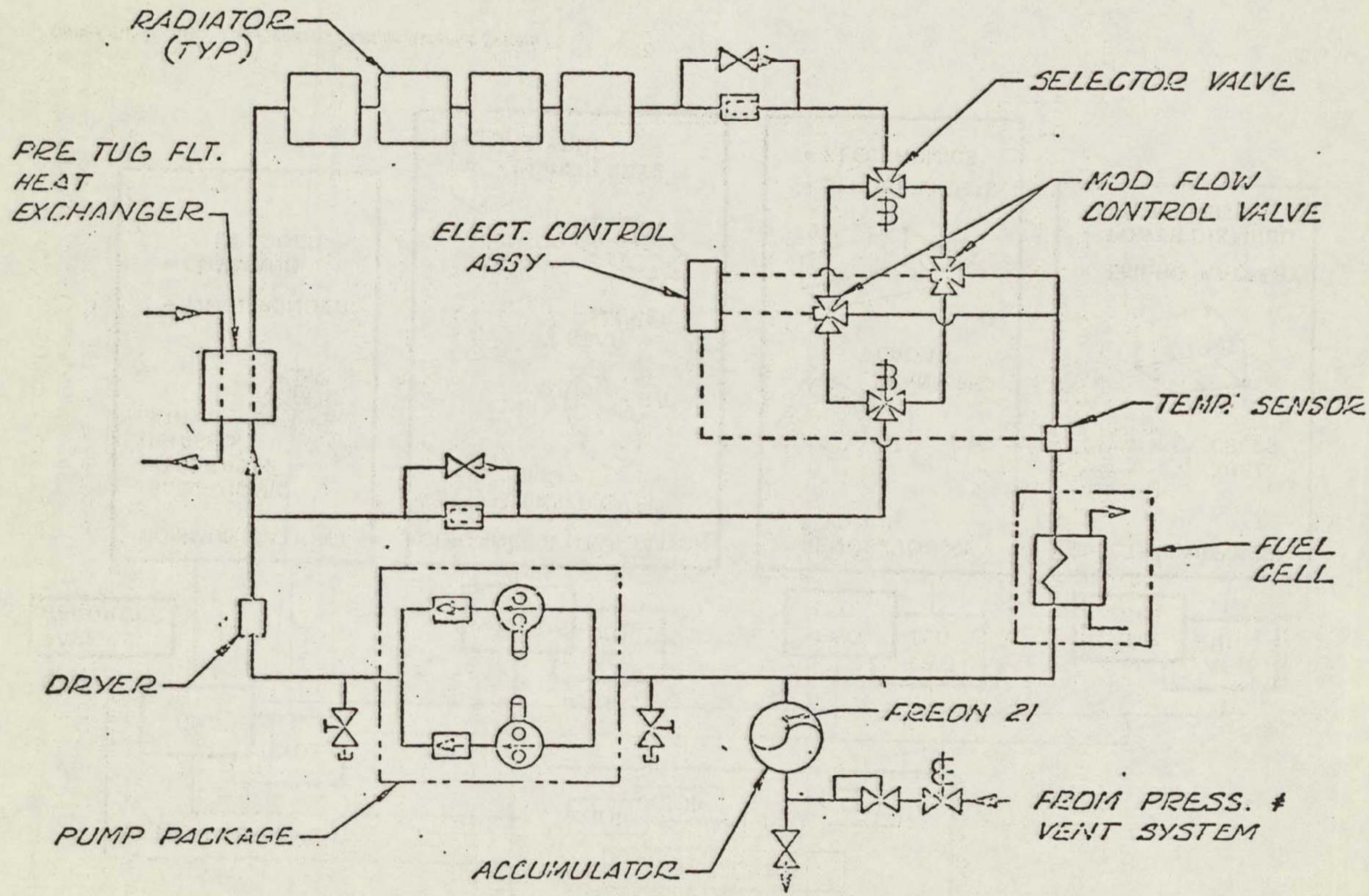

Figure 4.3.5-1. Space Tug Fuel Cell Thermal Control System

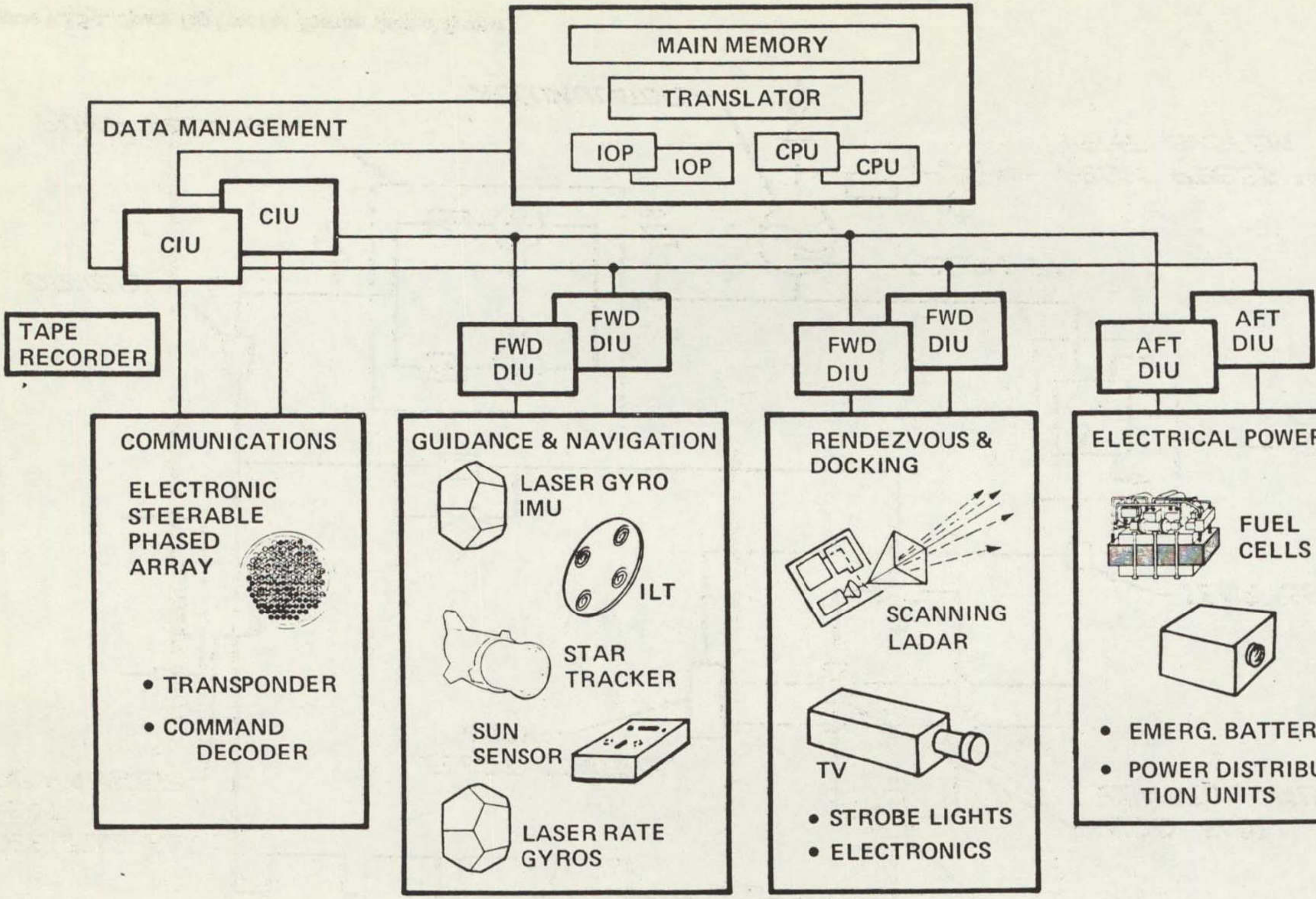

Figure 4.4.0-1. Space Tug Preferred Baseline Avionics System

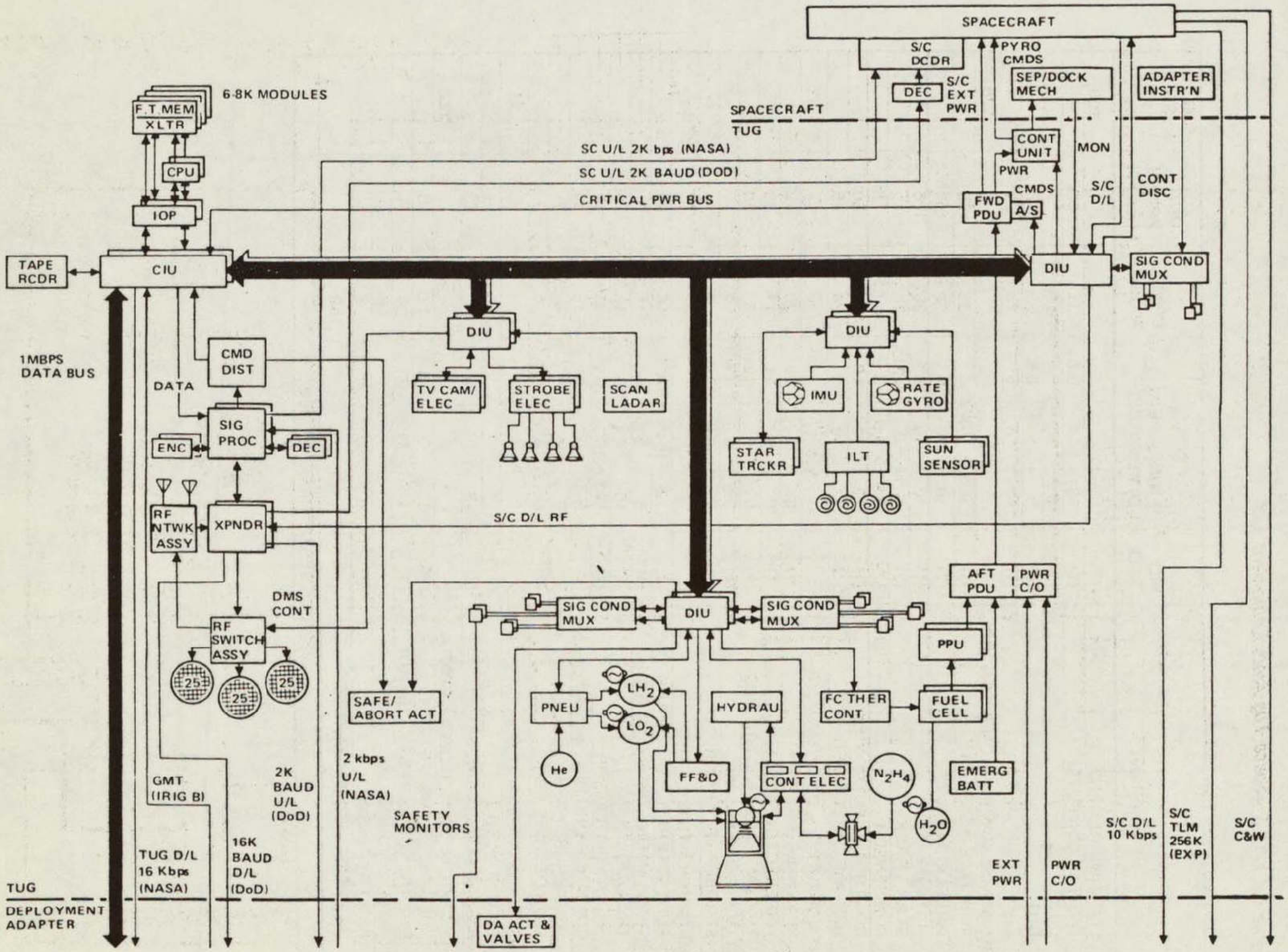

Figure 4.4.1-1. Space Tug Avionics Updated Baseline

Table 4.4.1-1. Space Tug Avionics Equipment List

EQUIPMENT	NO. REQ	ENVELOPE DIMENSIONS			UNIT WEIGHT	UNIT POWER (WATT)	SUB SYSTEM WEIGHT (LB)
DATA MANAGEMENT							100
DIGITAL COMPUTER	(1)	10	14	9.5	34	60	
CIU	(2)	5	5	6.5	6.5	7	
DIU	(8)	5	5	6.5	5	5	
TAPE RECORDER	(1)	10	8	5	13	20	
GUIDANCE, NAVIGATION & CONTROL							190
INERTIAL MEAS UNIT	(1)	9 x 9 DIA			25	100	
IMU ELECTRONICS	(1)	10	20	5	30	100	
RATE GYROS	(1)	10	10	6	20	100	
STAR TRACKER	(2)	6	8	12	16	12	
SUN SENSOR	(2)	6.9	6.5	3	4.5	5	
CONTROL ELECTRONICS	(1)	12	12	18	50	50	
ILT–ANTS./RECEIVER	(1)	12	10	9	24	15	
RENDEZVOUS & DOCKING							63
SCANNING LADAR	(1)	6	8	20	28	10	
& ELECTRONICS	(1)	9	9	11	11	30	
TV CAMERA & ELECTRONICS	(2)	6	6	15	8	10	
TV STROBE LAMPS	(4)	3.5	3.5	3.5	1		
STROBE ELECTRONICS	(2)	2	3.5	2.5	2		
COMMUNICATIONS							149
ELEC STEERED PHASED ARRAY	(3)	3.5 x 15 IN. DIAM			16	93	
OMNI ANT/NETWORK/SWITCH	(1)	5	5	6	11.3	3	
TRANSPONDER	(2)	15	7	6	16.5	16	
SIGNAL PROCESSOR	(2)	13.5	6	6.5	11	18	
COMMAND DISTRIB	(1)	5	5	4	18	35	
SGLS ENCRYPTER	(2)	6	4	5	4.3	7	
SGLS DECRYPTER	(2)	6	4	5	4	2.5	
INSTRUMENTATION							74
TRANSDUCERS	(243)				20	–	
SIGNAL CONDITIONERS	(3)	12	10	6	18	22	
ELECTRICAL POWER, DIST & CONTR							322
FUEL CELLS POWERPLANT	(2)	12	6	15	42	20	
EMERGENCY BATTERY (150 AH)	(1)	8	11	7	36	–	
PWR DISTRIBUTION					46	–	
PWR PROCESSING	(2)	9	9	8	8	–	
HARNESSES/SWITCHES/MISC					140		
AVIONICS SYSTEM WEIGHT 898 LB							

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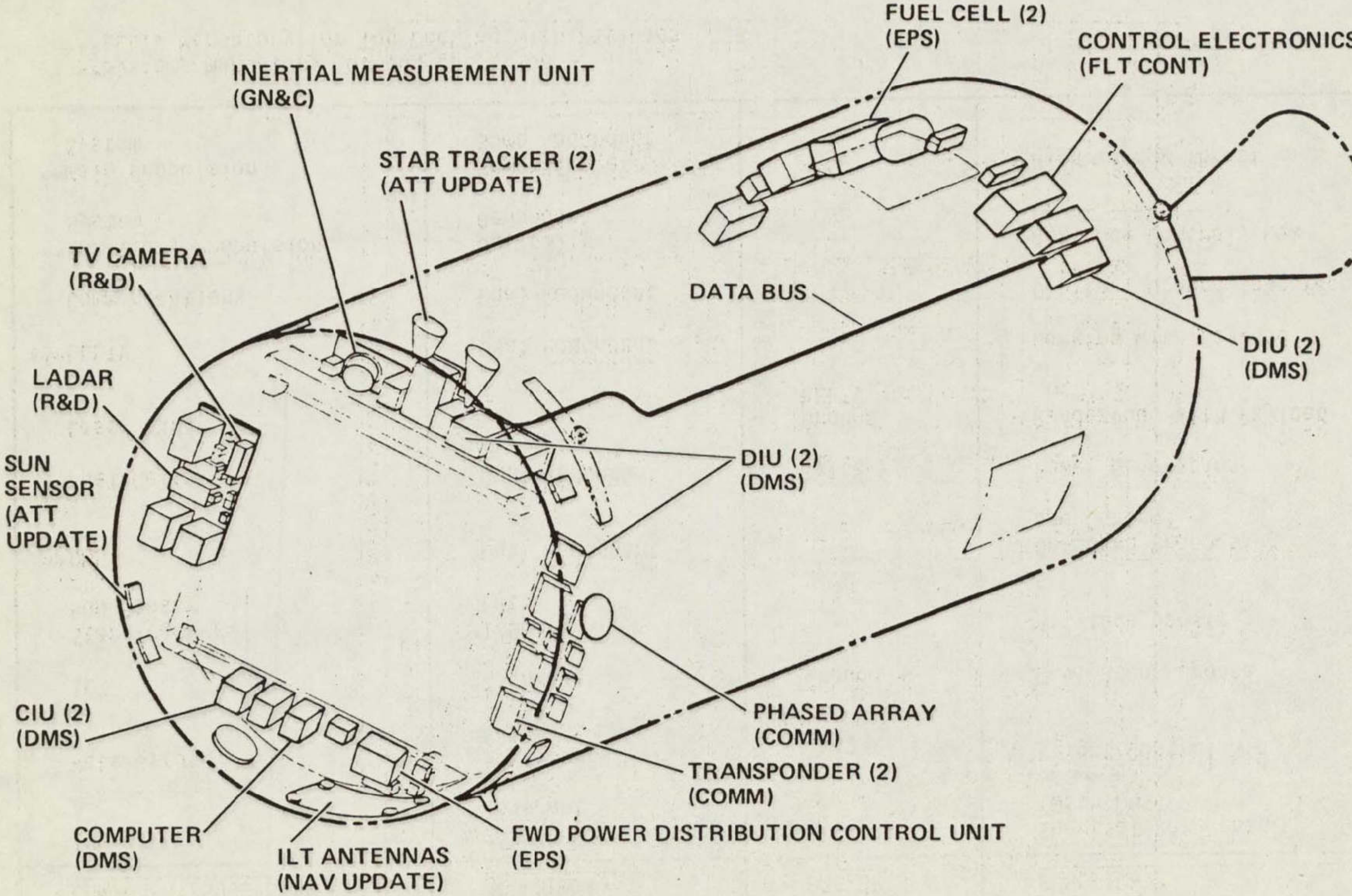


Figure 4.4.1-2. Typical Space Tug Avionics Installation Layout

Table 4.4.1-2. Tug Operational Redundancy Summary

COMPONENT/SUBSYSTEM	REDUNDNACY	BACKUP	FUNCTION
**IMU	2 Failures Tolerant	--	Inertial Reference (with DMS)
Rate Gyros	2 Failures Tolerant	--	Flight Control Aid
ILT	1 Channel	Ground	Navigation Update
Star Trackers, Sun Sensors	1 Spare Each	--	Attitude Update
**DMS	Dual Redundant	--	On-Board Processing and Control
**Fuel Cells	Dual Redundant	Battery	Power Generation
Laser Radar	--	Ground, LLLTV	Rendezvous with Payload
***LLLTV	Dual Redundant	--	Docking with Payload
Communications	Dual Redundant	--	Orbiter, Ground Interface
**Auxiliary Propulsion System	Basically Redundant	--	Attitude Control, Low Level Thrust
**Main Propulsion System	Some Simplex Some Redundant	--	High Energy Thrust

**Systems Mandatory for Tug Operation
***LLLTV Mandatory for Tug Docking with Payloads

input/output processor (IOP), computer interface units (CIU's), data busses, digital interface unit (DIU's) and a tape recorder. Present computer sizing includes 48K of 32 bit memory with a speed requirement of over 400 KOPS during burn phases. The computer software provides for all navigation, guidance and control processing, onboard components redundnacy management, telemetry processing (CIU), rendezvous and docking computations and sequencing for all Tug subsystems. The following gives a brief description of each component.

4.4.2.1 Main Memory

The main memory is baselined as a semi-conductor memory with high speed, low weight, low cost and high reliability. The memory has internal fault tolerant characteristics which, in conjunction with the translator, provides error checking and corrections in the event of malfunction. Spare bit planes replace malfunctioned bit planes when errors are detected. Forty-eight K of 32 bit memory is baselined.

4.4.2.2 CPU/IOP/CIU

The CPU provides the onboard processing capability for the Tug with a speed requirement of about 400 KOPS. The IOP controls the input and output operations to the CPU and with the CIU/data bus and processes the IMU input data. The CIU controls the data bus and provides the formatting for telemetry. These components operate in a prime/backup mode with bit and self-test providing the indications of failure and when backup mode are implemented.

4.4.2.3 Data Bus/DIU

The data bus system has two bus lines, command and reply, which are twisted shielded pairs and operate at a 2 MBPS rate. Four DIU's (eight with redundancy) are baselined and these provide the interface with all Tug and Spacecraft subsystems requiring process support or providing data for telemetry/record. Redundant DIU's are cross-strapped to each component to provide a fail safe path to all components. The use of the data bus, DIU's and CIU provide and integrate telemetry provided by other hardware on previous space programs.

4.4.2.4 Tape Recorder

The tape recorder is used to record data for maintenance purposes, especially during main engine burn phases. The recorder is baselined for 100 megabits of storage and has a read capability to allow playback of data through telemetry when ground communications are available.

4.4.3 <u>Guidance, Navigation and Control (GN&C) Subsystem</u>

The basic hardware elements of the GN&C subsystem and their functions are as follows:

- Laser IMU - inertial reference
- Interferometric Landmark Tracker (ILT) - state vector update

- Star Tracker and Sun Sensors - attitude update
- Laser Rate Gyros - flight control sensor

The guidance, navigation, and control computations are performed in the onboard digital computer using input data provided from the above sensors and feedbacks from the control elements. The baseline components, including software elements, are shown in Figure 4.4.3-1. The following gives a brief description of the GN&C components and their functions.

4.4.3.1 Inertial Measuring Unit (IMU)

The IMU is a laser gyro dodecahedron which provides the capability for proper operation even after two gyro and two accelerometer failures. The onboard digital computer maintains the attitude, velocity and position states. Vehicle movements are detected by the IMU and its outputs are sent to the computer for continuous state vector and attitude computations. The IMU software includes the compensation and failure detection capability required for the IMU, and some limited BITE capability is available.

4.4.3.2 Interfermetric Landmark Tracker (ILT)

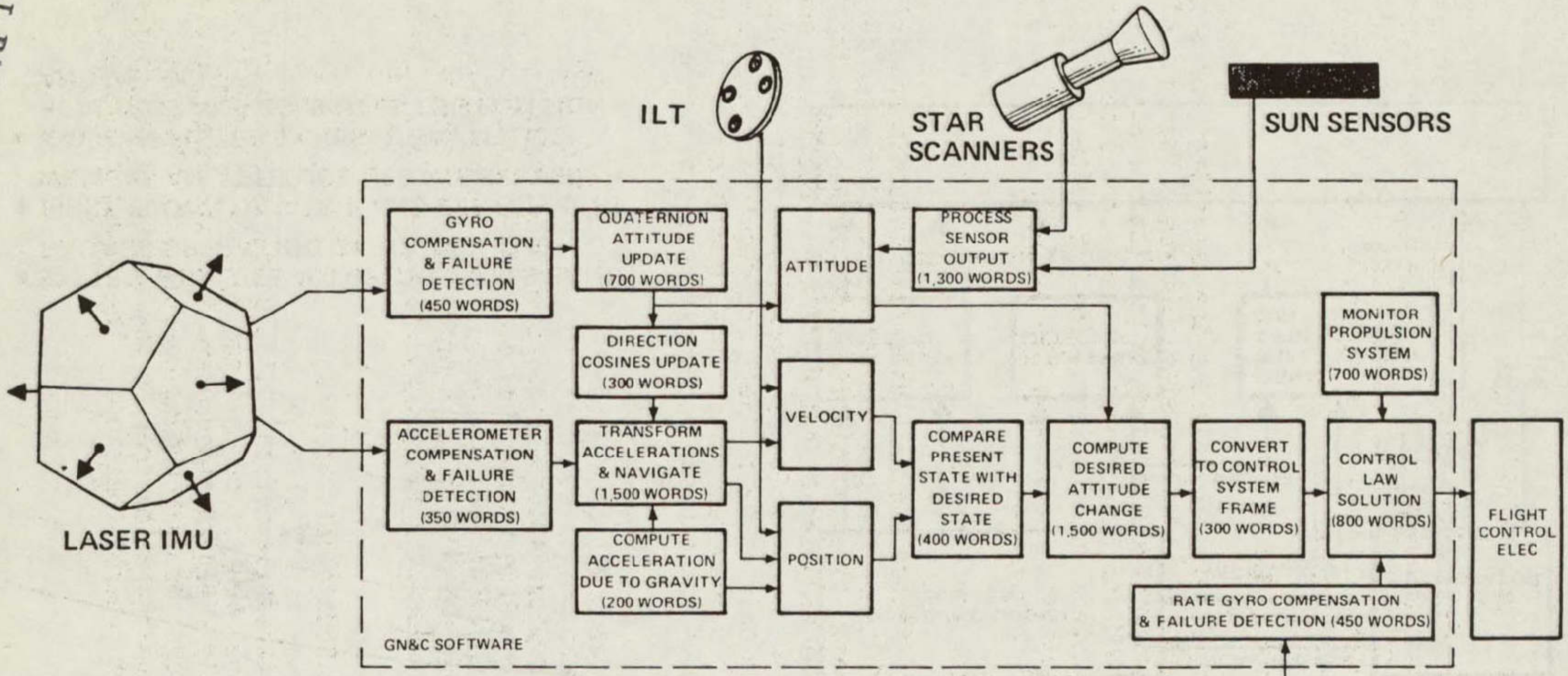
The ILT, shown schematically in Figure 4.4.3-2, uses four antennas receiving the same ground-generated radar signal to provide data to the computer for state vector update computations. Time phase differences between the input signals to the four ILT antennas are used to determine the direction of the generating radar station and subsequent software comparisons provides data for the required update. Since only three channels are required for proper operation, the fourth channel provides redundancy to accommodate one failure. An injected RF signal can be used for closed loop verification of proper ILT operation.

4.4.3.3 Star Tracker and Sun Sensor

The star trackers and sun sensors provide the required onboard capability for autonomous attitude updates. One star tracker and one sun sensor are operated simultaneously to provide the complete attitude orientation information required. Both sensors are dual redundant, and provide a light source for self-test capability. Sensor redundancy management and sensor data processing is provided by the computer.

4.4.3.4 Rate Gyros and Flight Control Electronics

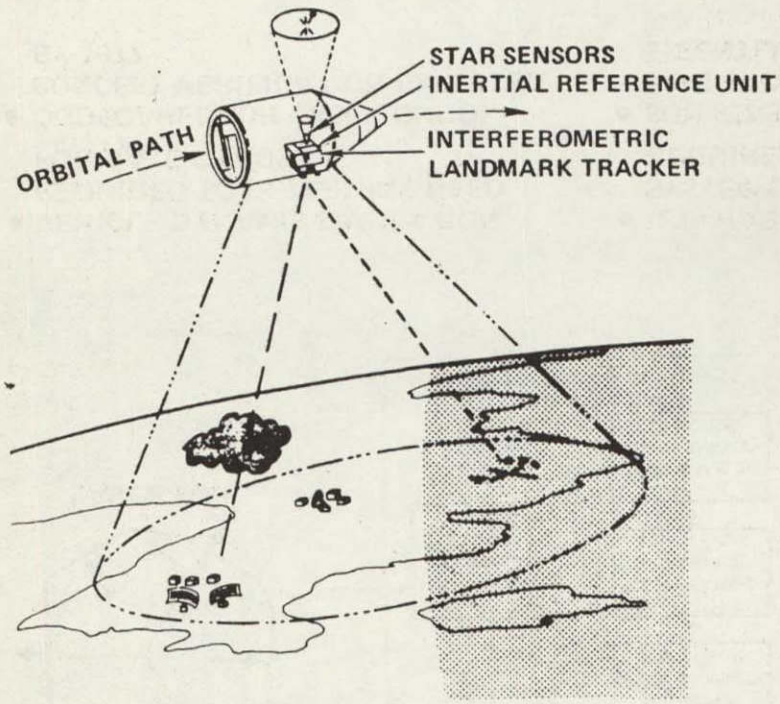
The Tug computer provides the thrust vector and attitude control commands and monitors error signals for proper vehicle control and maneuvers. The thrust vector control systems uses triple redundant servoamplifiers driving triple redundant, voting servoactivators for main engine positioning. The laser rate gyros in a dodecahedron configuration provide for inputs to the control law equations to aid the flight control functions. The computer manages the rate gyro redundancy.



- VEHICLE DYNAMIC SIMULATION REQUIRED TO DETERMINE NEED FOR RATE GYROS
- DODECAHEDRON LASER GYRO—CONCEPT VERIFICATION EXPECTED BY 1977
- ILT—HARDWARE IS AVAILABLE, SYSTEM CONCEPT VERIFICATION REQUIRED
- SUN SENSORS, STAR TRACKERS, AND FLIGHT CONTROL ELECTRONICS ARE ESSENTIALLY OFF THE SHELF

Figure 4.4.3-1. Space Tug Baseline GN&C Subsystem

OPERATION



- SYSTEM WILL USE 400 OF THE 8000 S-BAND RADARS OPERATING 24 HOURS A DAY
- FIRST FLOWN ON ATS-F AND PERFORMING WELL AS AN ATTITUDE UPDATE SYSTEM
- KALMAN FILTER TAKES ILT ATTITUDE READINGS AND COMPUTES TUG POSITION AND VELOCITY

ILT HARDWARE

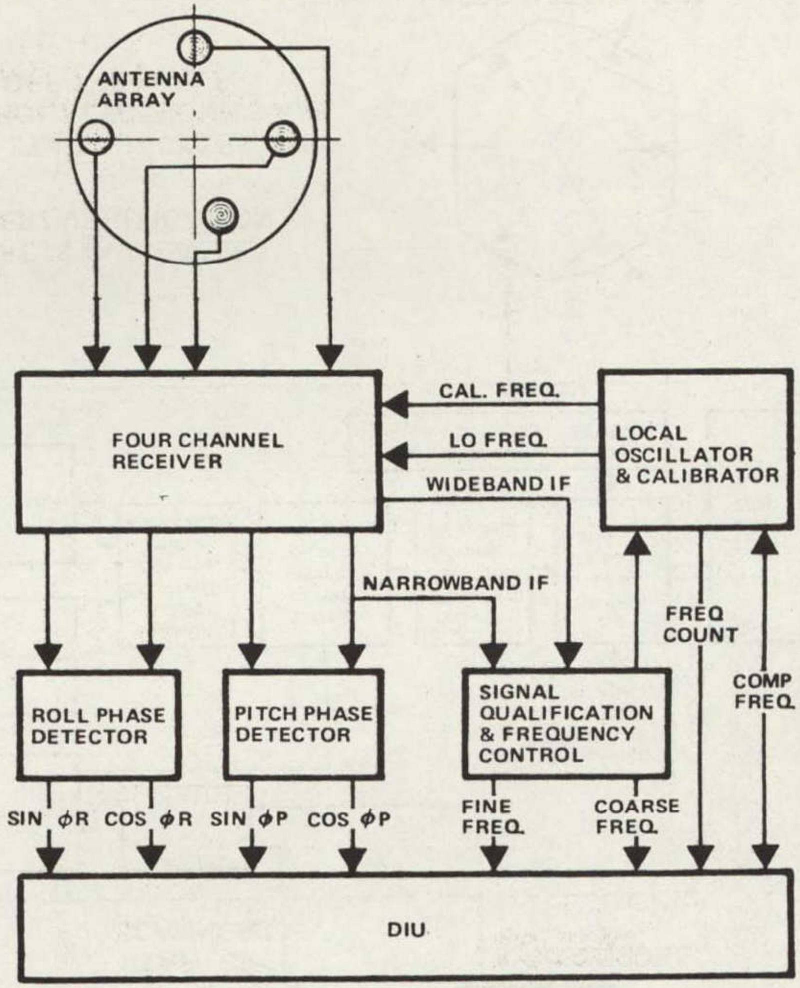


Figure 4.4.3-2. Space Tug Interferometric Landmark Tracker (ILT)

4 4 4 Communication Subsystem

The communication subsystem, shown in Figure 4 4 4-1, consists of three 25 element phased array antenna systems which provide integrated tracking, telemetry and command interface capability with the Orbiter and ground. The system has provisions for both directional steering and omnidirectional capabilities The communications interface with the Tug is also shown on Figure 4 4 4-1 The system is essentially dual redundant for all subsystem components The communications will be activated during the Tug deployment sequence and deactivated during the recovery operations

4 4 5 Rendezvous and Docking Subsystem

The rendezvous and docking subsystem presently baselines a scanning laser radar (SLR) for the rendezvous with Spacecraft and a low-light-level TV (LLLTV) for remote man-in-the-loop docking with Spacecraft The LLLTV is also used for visual inspection of Spacecraft

The SLR, as shown in Figure 4 4 5-1, in conjunction with the Tug DMS provides the capability for autonomous rendezvous with Spacecraft The SLR provides range and angle data to the DMS, which provides the proper maneuver commands to achieve rendezvous to within approximately 30 feet of the target. Only a single SLR is baselined for the Tug, however, the ground tracking plus the LLLTV can be used to accomplish the rendezvous in the event of a SLR malfunction

The LLLTV with a man-in-the-loop is the proposed candidate for docking with the Spacecraft and for visual inspection A block diagram of the proposed system is shown in Figure 4 4 5-2 This shows the camera, lights and electronics for the TV system as well as the ground interface and Tug computer support required for the docking operations The LLLTV system is dual redundant In the event malfunction of both systems, no backup capability is available for docking

As shown in Figure 4 4 5-2, an extensive ground interface with continuous ground communications is required for the docking operations This would be a ground interactive system with ground commands controlling the Tug operation based on input data supplied by the LLLTV, and this is a major impact on flight control operations.

4 4 6 Electrical Power Subsystem

The electrical power subsystem consists of dual redundant fuel cells which generate power for the Tug, and emergency battery for contingency operations, distribution and control components. A new technology lightweight fuel cell is baselined The Tug power subsystem is dual redundant with automatic and DMS control provided in the subsystem

The Orbiter provides power to the Space Tug during all phases when the Tug and Orbiter are attached The Space Tug fuel cells will be activated during prelaunch to supplement the Orbiter-provided power during Orbiter ascent and burn phases The Orbiter power will be disconnected just prior to Tug deployment and reconnected after retrieval

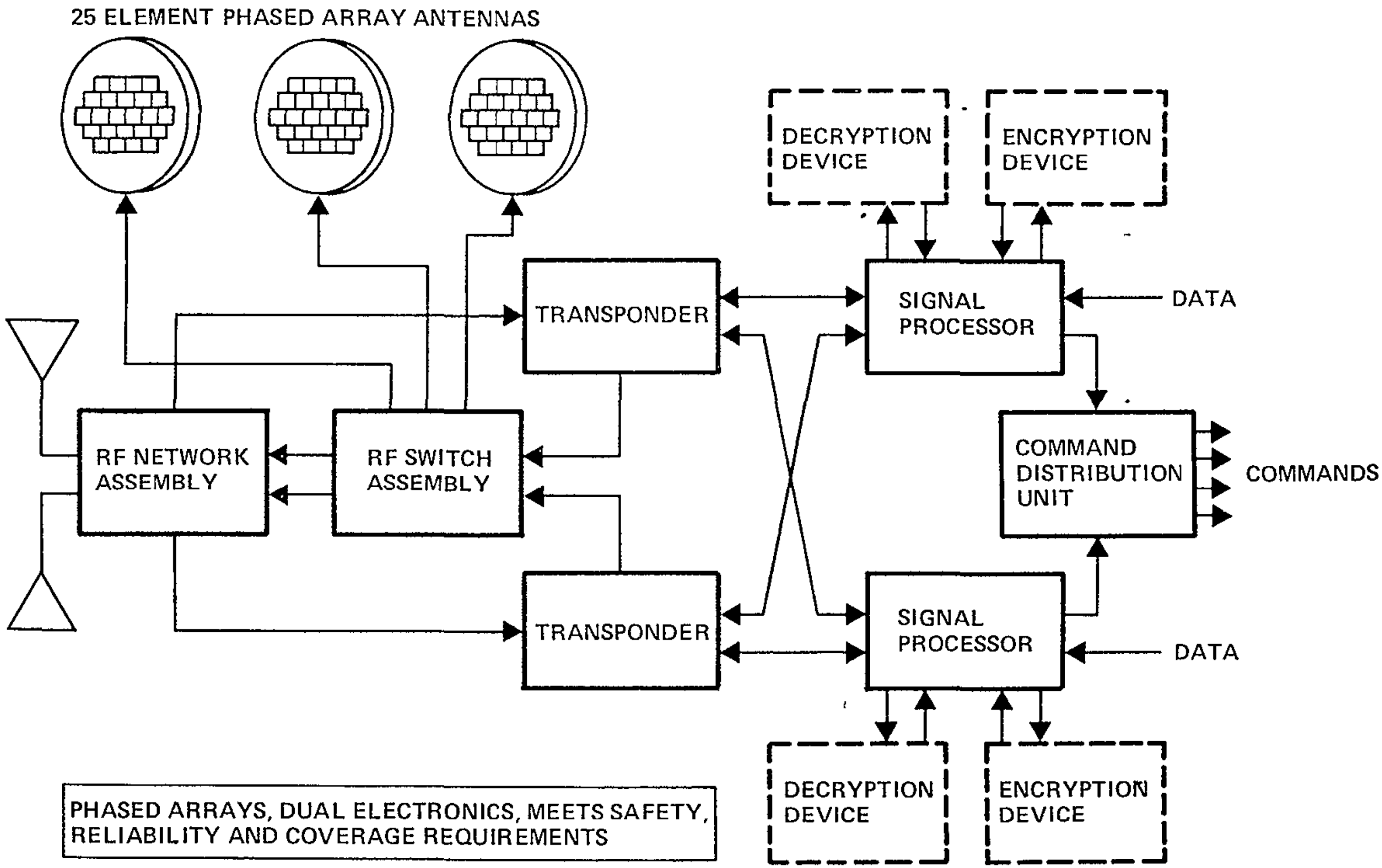


Figure 4 4 4-1 Space Tug Baseline Communications System

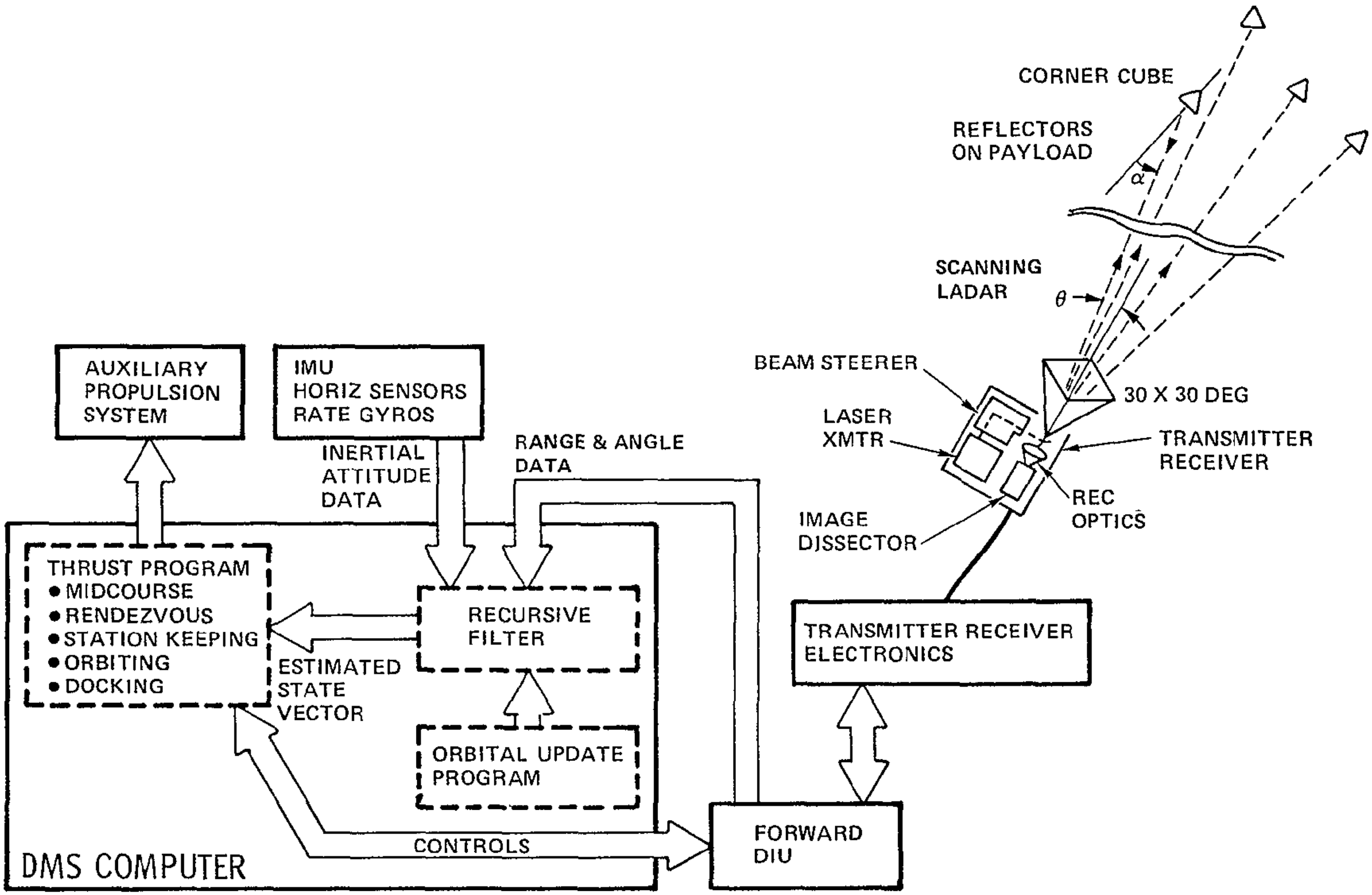
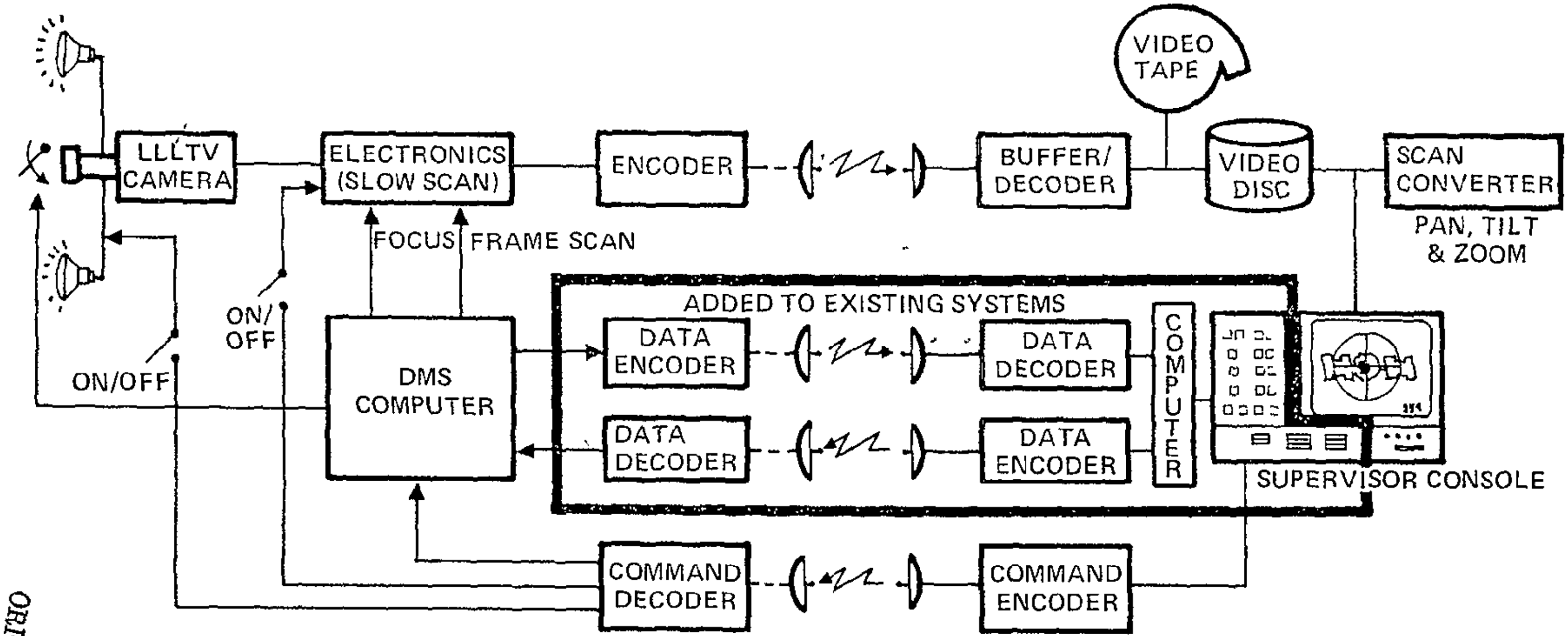


Figure 4.4 5-1. Rendezvous and Docking Subsystem Autonomous GaAs SLR Candidate



SPACEBORNE LLLTV SYSTEM

- 525 LINE RESOLUTION
- 3 FRAMES/MIN (MAX)
- STROBE DOCKING LIGHTS

GROUND SYSTEM

- VIDEO DISC RECORDER
- SCAN CONVERTER
  - X Y JOYSTICK
  - ZOOM CONTROL
- VIDEO TAPE RECORDER
- VIDEO DISPLAY
- SUPERVISOR CONTROLS

Figure 4 4 5-2 Rendezvous and Docking Subsystem Man-In-The-Loop Candidate

4 4 7 Measurement Subsystem

A Space Tug measurement subsystem was designed to provide signal conditioning and measurements for the Tug Approximately 200 total measurements were baselined for the Tug and these are summarized in Table 4 4 7-1. For operational analysis for the Tug, it was assumed that approximately 60 C&W and safety related parameters and 40 subsystem status related parameters were provided to the Orbiter during attached and proximity operations The measurement system interfaces directly with the DIU's for input to and processing by the Tug DMS The measurements are processed by the DMS and routed as telemetry to communication link (or Orbiter hardware interface) as required

Table 4 4 7-1 Tug Measuring System Parameters

ENGINE		STAGE	
Temperature	5	Temperature	15
Pressure	7	Pressure	20
Position	4	Vibration	15
Speed (RPM)	1	Flow	2
Vibration	1	Position	20
Other	6	Voltage	36
	24	Liquid Level	12
		Depletion Sensors	7
		Strain	20
		H_2 Leak Sensors	8
		O_2 Leak Sensors	8
		Gas Analysis	3
		Contamination	10
			176

SPACE TUG OPERATIONAL INTERFACE ANALYSIS 5

The Space Tug operational interfaces required analysis to determine their capability as they related to mission operations This was done by analyzing the baseline requirements as defined in Section 2 0 to determine what various interfaces were required to accomplish Systems capabilities were then analyzed on both sides of all interfaces This was possible in varying depths depending upon stages of development With requirements and interfacing system capabilities, the interfaces could be defined in terms of mission operations to determine adequacy and further define mission operations It was an iterative process, building upon improved definition to better the understanding of the problem and to improve the solution The parallel studies were used heavily to define the Tug, the Spacecraft, the Tug interfaces, and the operational requirements

JSC's documentation, mainly Volume XIV Space Shuttle System Payload Accommodations Rev C thru change 7 was used heavily to define the Shuttle accommodation for the payloads, in this case the Tug

Tug Operational Interface Definition - The Space Tug interfaces with the Orbiter, the Spacecraft (payloads), the Ground Support Equipment (GSE) and the Tug Operations Center (TOC) for flight operations interfaces One or more of these interfaces are available, although not always continuously, for mission phases from prelaunch operations through deployment, payload replacement/retrieval, Orbiter retrieval and landing operations The interfaces provide the operational data exchange for the various phases required for flight operations and flight control Figure 5 0 0-1 shows the Tug data interfaces during preflight operation, and the Tug data interfaces after liftoff during all phases that the Tug and Orbiter are attached Figure 5 0 0-2 shows the Tug data interfaces during flight phases when the Tug and Orbiter are detached This section will discuss the Tug data interfaces (Spacecraft/Orbiter interfaces not included) and the types of data exchange required for each interface. The interfaces shown are a combination of Orbiter and ground support capabilities, Tug/SC data requirements and the design implementation used by the Tug and SC

5 1 TUG/ORBITER INTERFACE

The Tug/Orbiter interface received the most attention because it is the most active (time and volume of data exchanged) It is also the most urgent to define because of potential design impacts to the Orbiter

5 1 1 Orbiter Payload Interface Support

The Orbiter provides a wide variety of interface capability for the varying payloads to be carried Figure 5 1 1-1 gives an overview of the avionic interfaces available for payloads, such as the Tug, and the associated paths for the data As shown, the Orbiter provides interfaces for the following types of data which are useful to the Tug

- Engineering Data - 16 KBPS to the Payload Signal Processor (PSP) and up to 5 channels of up to 64 KBPS each multiplexed through the Payload Data Interleaver (PDI)

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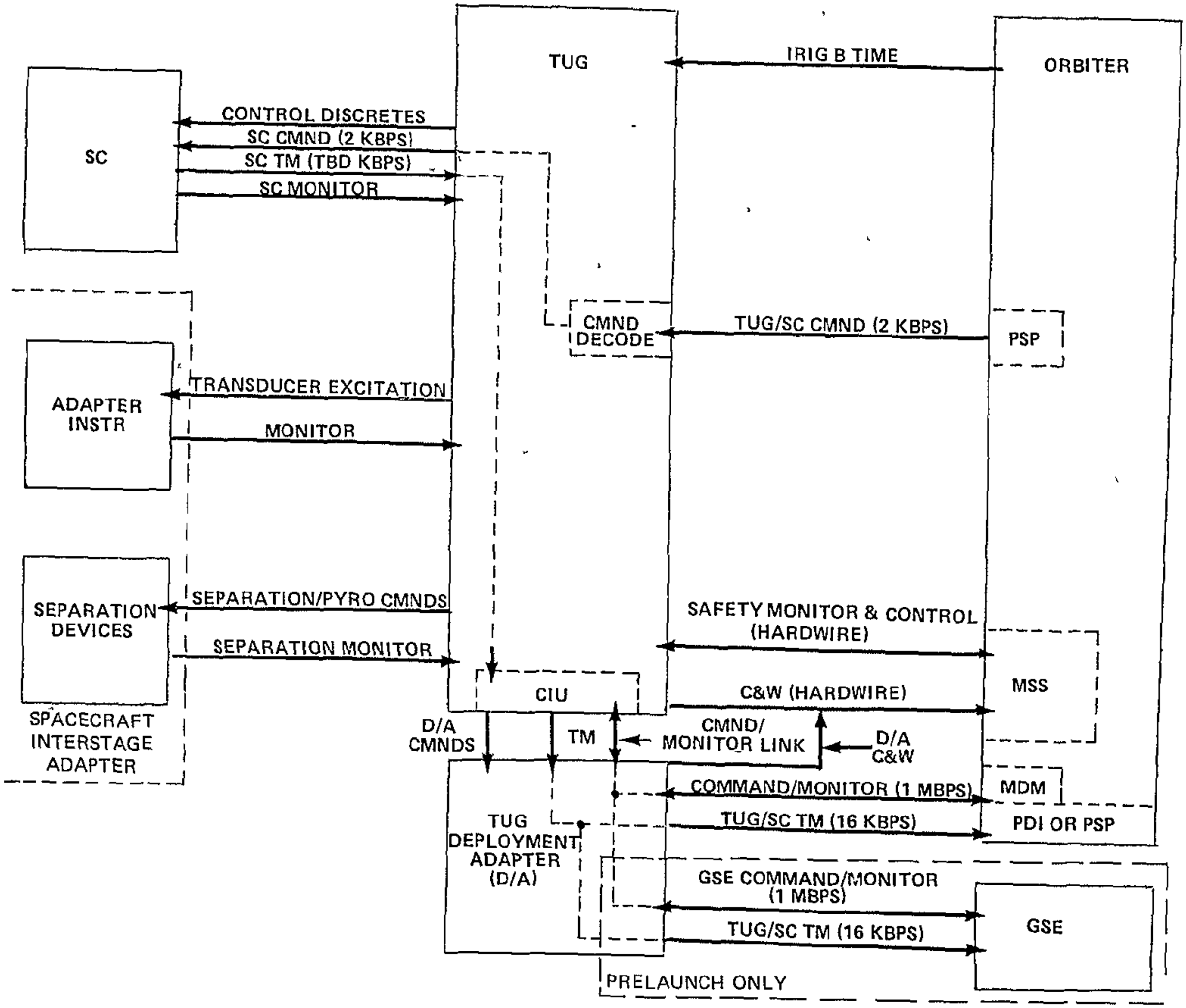
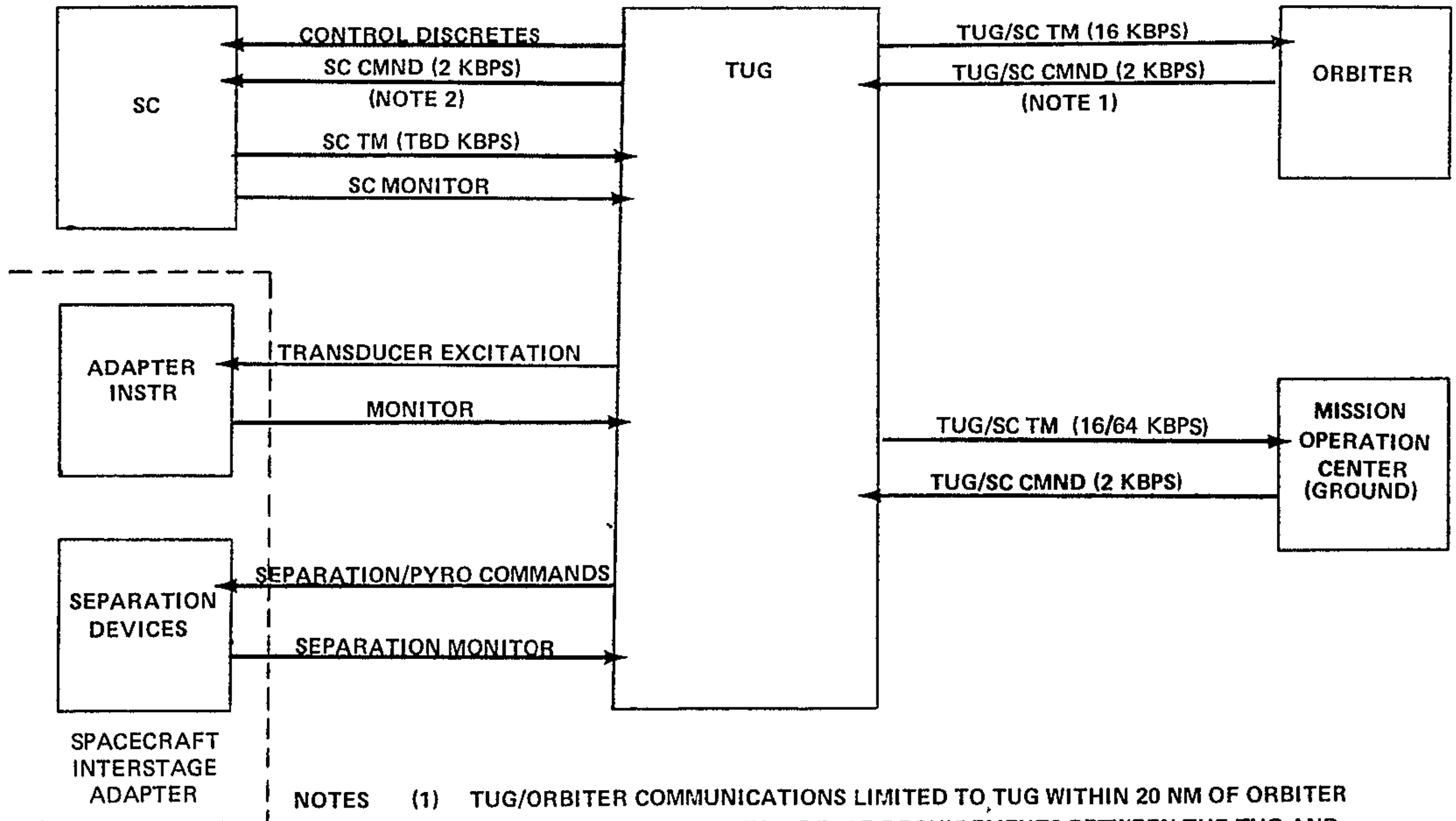


Figure 5 0 0-1 Tug Operational Interfaces - Tug/Orbiter Attached



NOTES (1) TUG/ORBITER COMMUNICATIONS LIMITED TO TUG WITHIN 20 NM OF ORBITER

(2) THERE ARE NO ACTIVE INTERFACE REQUIREMENTS BETWEEN THE TUG AND SPACECRAFT AFTER SPACECRAFT SEPARATION

Figure 5 0 0-2 Tug Post-Deployment Operational Interfaces - Tug/Orbiter Detached

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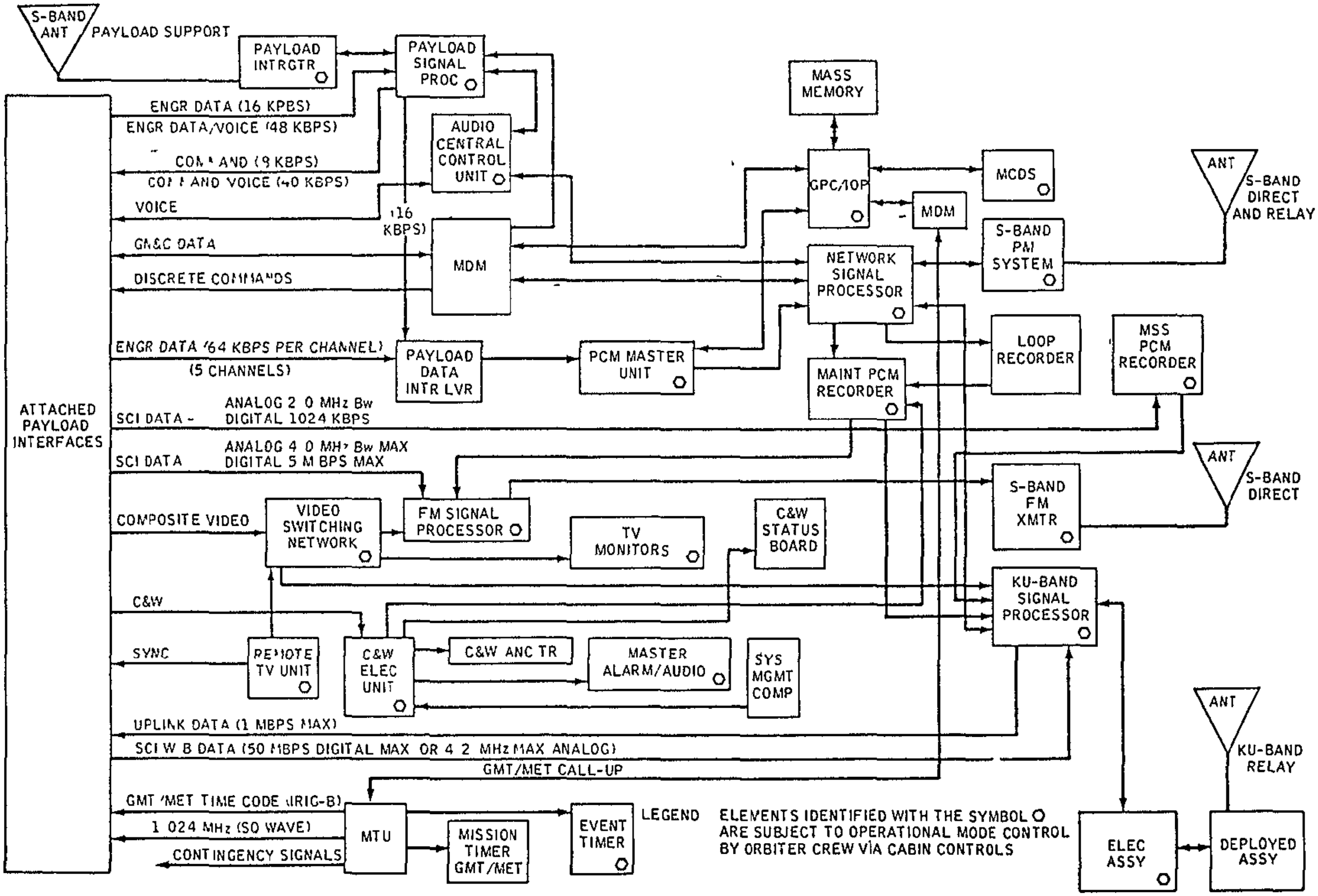


Figure 5.1.1-1 Orbiter Avionics Functional Diagram for Payloads

- Command/Data Input - 2 KBPS (8 KBPS) command link from the PSP, GN&C data to/from the Tug and discretes from the Multiplexer/Demultiplexer (MDM)
- Caution and Warning - input capability for hardwire C&W signals to the C&W Electronics Unit
- Timing - timing signals from the Orbiter Master Timing Unit (MTS)

In additional, high data rate interfaces are available for scientific data not required for the Tug, but may be used by the Spacecraft (SC)

The Orbiter has allocated approximately 10K of 32 bit words in main storage and approximately 18 KOPS for payload (Tug/Spacecraft) support in its general purpose computer

The Mission Specialist Station (MSS) and Payload Specialist Station (PSS) also have space available for Tug dedicated interface panels See Figure 5 1 1-2 which shows potential placement of non-standard avionics to support Tug operations Figure 5 1 1-3 gives typical layouts of the control display panel in the Orbiter which will support the Tug operations As shown, these C&D interfaces include status, deploy operations, Tug commands, abort sequences and manual control of Tug elements

5 1 2 Tug/Orbiter Interface Overview

5 1 2 1 Prelaunch/Flight

The Tug/Orbiter prelaunch and flight data interfaces are summarized in the right half of Figure 5 0 0-1 and include all mission phases when the Tug and Orbiter are physically attached The Orbiter provides IRIG B timing signals to the Tug from its master timing unit Ground commands (2 KBPS) to either the Tug or Spacecraft are routed through the Orbiter Payload Signal Processor (PSP) and relayed to the Tug command decoder Tug commands are processed by the Tug and Spacecraft commands are routed to the Spacecraft for execution

The Tug and Spacecraft telemetry, for Orbiter and/or ground use, is routed from the Tug through a multiplexer in the Tug Deployment Adapter (D/A) to the Orbiter or Payload Data Interleaver (PDI) This link contains the housekeeping/status data required to evaluate the Tug and Spacecraft

The hardwire data links between the Tug and Orbiter provide the Caution and Warning (C&W) signals to the Orbiter displays through the C&W system and provide a means of issuing time-critical safety commands The 1 MBPS command/monitor link is routed through the Deployment Adapter to the Orbiter and provides a means of obtaining the Tug C&W (backup) and safety critical parameter (primary) as well as the command capability to execute safety related commands as required In addition, this 1 MBPS link provides the Orbiter/Tug data link (through the D/A) to provide data required by the Tug, such as a Navigation Update, and to receive status and verification data required by the Orbiter to monitor Tug activities, such as IMU activation

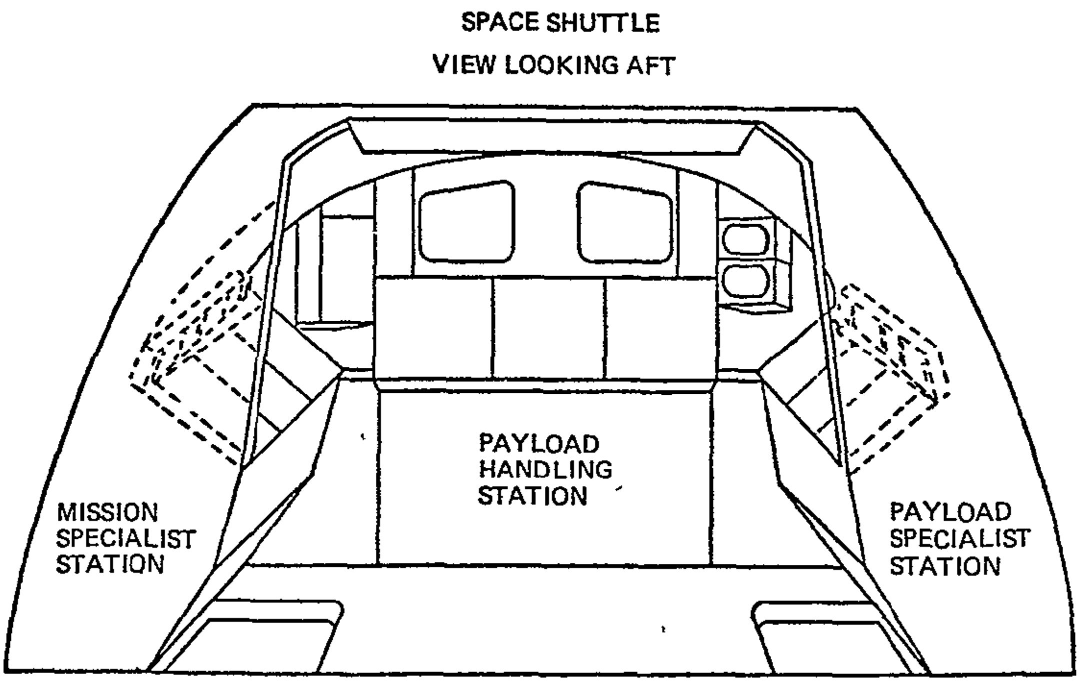


Figure 5 1 1-2 Orbiter I'SS/PSS Layout Schematic

It is assumed that a standarized 16 KBPS link will provide the safety and operational data required by the Orbiter for both attached and detached modules For standard interface this link would be routed through the Orbiter PSP If it is found that more than 16 KBPS is required for Orbiter and/or ground interface while the Tug and Orbiter are attached up to 64 KBPS of data could be routed through the Orbiter PDI for Orbiter use or for S-Band transmission to the ground In addition, up to 50 MBPS could be routed through the Orbiter Ku-Band link to the ground

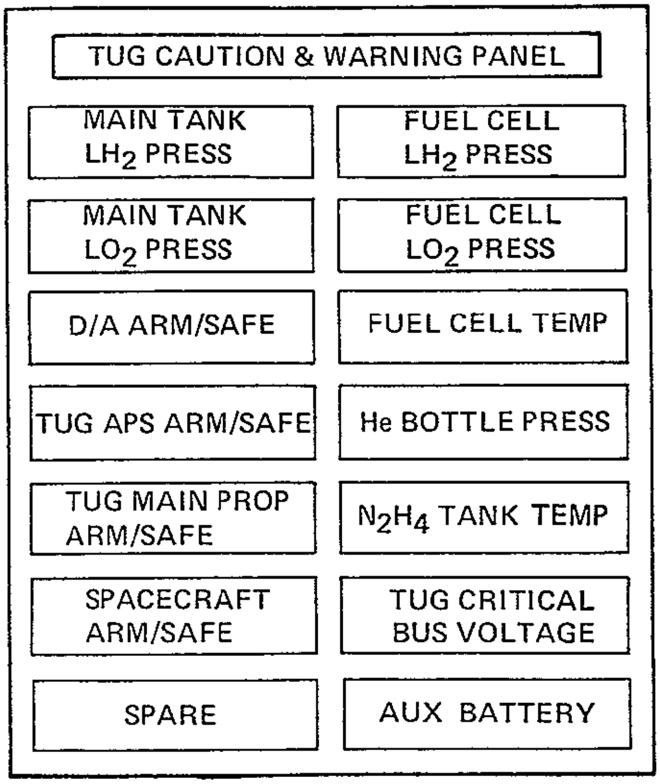
5 1 2 2 Post-Deployment

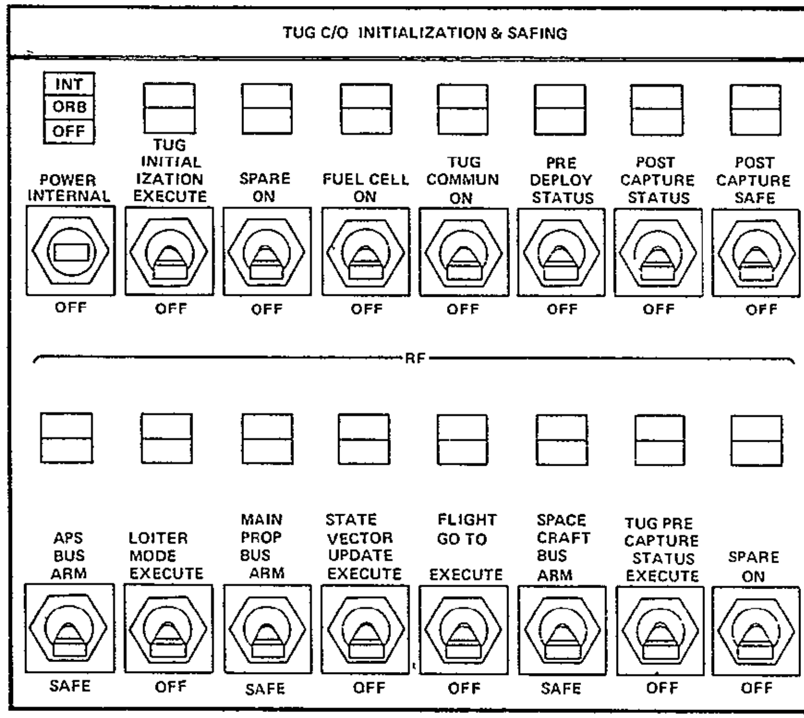
The Tug/Orbiter post-deployment data interfaces are shown in the upper right of Figure 5 0 0-2 and includes the deployment and retrieval phases when the Tug and Orbiter are detached and within 20 NM of each other As shown, the only data interfaces between the Tug and Orbiter are the telemetry and command interfaces which include both Tug and Spacecraft data

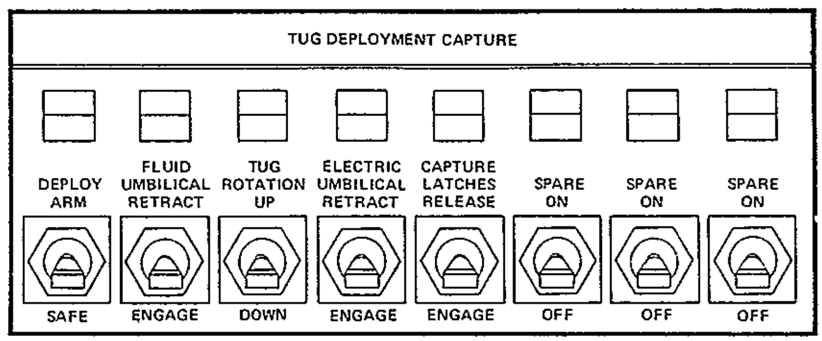
The telemetry link is required to provide Tug and Spacecraft C&W, safety related and status data to the Orbiter to determine their health during deployment and retrieval operations. The 16 KBPS RF data link is provided to the Orbiter PSP The command link allows the Orbiter to control safety critical Tug/SC parameters during near vicinity operations and to provide backup capability for critical activation signals as required

5 1 3 Caution and Warning Description

The caution and warning implemented in the Orbiter for safety monitoring of Tug parameters is treated here for completeness of the Tug/Orbiter interface analysis To summarize, the Orbiter C&W system, as it interfaces with the Tug as a payload, is undefined (TBD) by the Orbiter at this time See Figure 5 1 3-1







ADDITIONAL CREW MONITORING CAPABILITY

- ACCESS TO THROUGH ORBITER TUG GROUND TELEMETRY
- MSS CRT & KEYBOARD ACCESS TO DATA STREAM

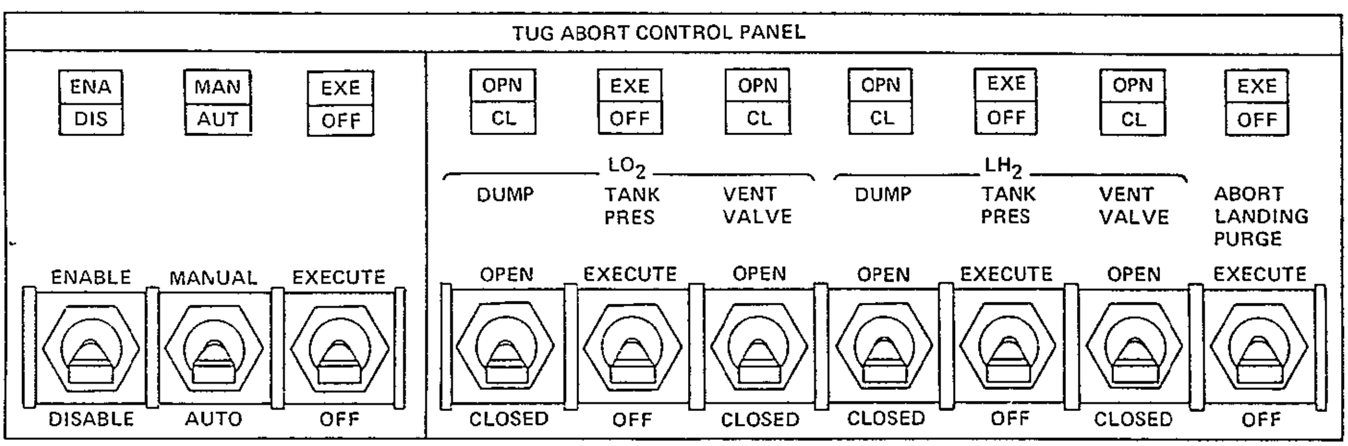


Figure 5 1 1-3 Orbiter Panels for Tug Control/Monitoring

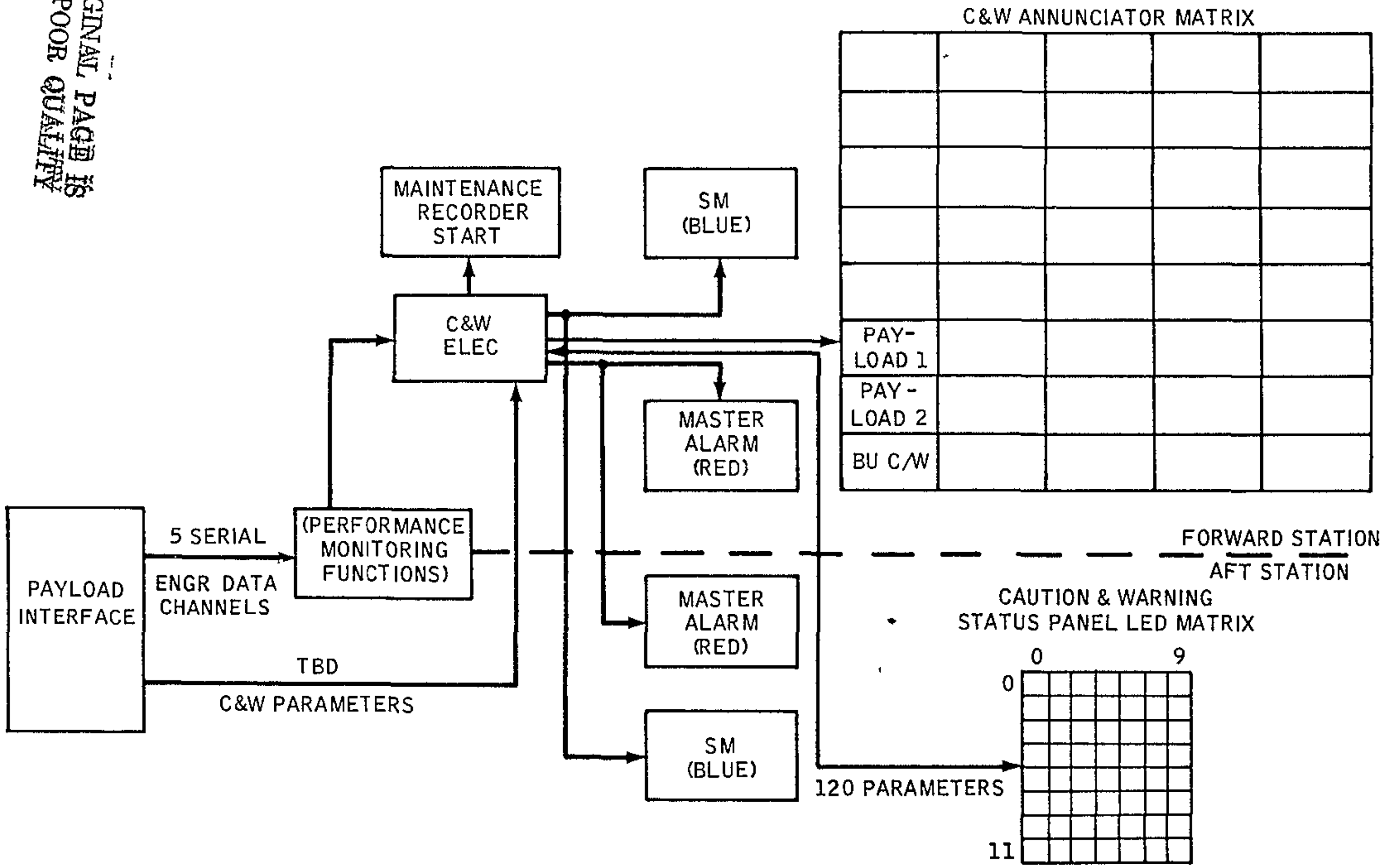


Figure 5 1 3-1. Current C&W Definition

The work done from Orbital Operations point-of-view is summarized below

- The Tug safety requirements were analyzed in Section 2 4 and the "Tug Operational C&W Status Measurements and Annunciators) recommendations appear in Section 2 4 3
- A complete "Space Shuttle C&W Definition as Related to Space Tug" is contained in Appendix B of this volume.
- The Orbiter definition of the Payload C&W is shown in Figure 5 1 3-1 which is from Change No 7 to JSC Volume XIV Payload Accommodations and, therefore is its current definition When it is compared to the similar Figure 3 in Appendix B, it is seen to be now accommodating TBD C&W parameters for payloads and is also now pictured a less powerful syste

5 1 4 Tug/Orbiter Operational Interactions

The following is a summary of Space Tug/Orbiter operational interactions (See Table 5 1 4-1)

The Orbiter monitors the Tug C&W and safety related parameters to assure Orbiter crew safety and provides the switching capabilities to correct any detected malfunctions These safety parameters are monitored and controlled while the Tug is in the cargo bay or in the near vicinity of the Orbiter

The Orbiter will provide the capability to initiate safety or deployment critical functions during Tug deployment, and will monitor the results of those actions to assure the events have been accomplished The critical activation items include power transfer, IMU and communications activation, and APS activation The Orbiter will control all mechanisms, such as latches and umbilicals, which relate to deployment

The Orbiter will monitor the status of safety or mission critical subsystems to assure mission accomplishment, however, the detailed Tug status will be the prime responsibility of the ground Corrective commands, which are not safety critical, will be issued by the ground and routed through the Orbiter for Tug malfunction and contingency operations

The Orbiter has a similar relationship with the Spacecraft while attached to the Tug C&W monitors and controls for the Spacecraft are available in the Orbiter Spacecraft wideband data is sent direct to the Orbiter not thru the Tug Spacecraft telemetry and RF uplink commands are sent to/from the ground thru the Tug and Orbiter

5 2 TUG OPERATIONS CENTER (TOC) INTERFACE

The Tug RF link to the ground and return link provides the capability for communications with the Tug Operations Center (TOC) after Tug deployment by the Orbiter This interface is shown in Figure 5 0 0-2 and may be relayed through the STDN or TDRS to the TOC The command link provides a 2 KBPS capability for operational or contingency commands to either the Tug or Spacecraft while they are attached The downlink provides status and operational data to the TOC from both the Tug and Spacecraft The downlink required capability is 16/64 KBPS for LLLTV After Spacecraft separation, the Spacecraft will provide its own ground interface capability

Table 5 1.4-1. Summary of Space Tug/Orbiter Operational Interactions

- Safety Monitoring and Controls
  - Tug C&W/BU C&W (Pressures, Temperatures, Busses Safe, Bus Power)
  - Orbiter Switches to Correct C&W Conditions
- Tug Activation, Deploy, Retrieval, Safing Monitoring and Controls
  - Orbiter Switches to Accomplish Requirements of the Above Phases
  - Feedbacks to Lights Indicate Tasks Accomplished
- Tug Status Monitoring and Commanding (Largely Fed Thru Orbiter To/From Ground Control)
  - Detailed Tug Status (C/O) Prime Responsibility of Ground
  - Contingency Commanding Possible From Ground
- Spacecraft/Tug/Orbiter Operational Interactions Similar to Many of the Above Functions in Wide Spectrum Depending on Payload
  - Spacecraft Wideband Data — Largely Fed Thru Orbiter To/From Ground Control
  - Spacecraft TLM
  - Spacecraft RF Command Uplink
  - Spacecraft C&W and Switches to Correct Conditions

5 3 TUG/SPACECRAFT INTERFACE

The Tug/Spacecraft interface exists from prelaunch through Tug/Spacecraft separation and are shown in Figures 5 0 0-1 and 5 0 0-2 There are no active Tug/Spacecraft data interfaces after their separation and Tug/Spacecraft interfaces for SC retrieval, servicing, spin/despin have not been defined at this time Other Spacecraft/Orbiter and Spacecraft/Ground links exist, but are not included in this study

The Tug/Spacecraft command and telemetry interfaces essentially routes the required Spacecraft telemetry and command data to/from the ground and/or Orbiter This interface allows SC status and backup C&W signals to be multiplexed in the Tug telemetry stream and SC commands received when no independent SC communication capability exists. The amount of SC telemetry to be included in the Tug 16 KBPS link is variable up to 10 KBPS

Other Tug/Spacecraft data links provide the required control/monitor capability for the Tug to perform selected SC sequences prior to separation, such as activation, and to monitor status and feedback as required.

5 4 TUG/GSE INTERFACE

The Tug/GSE interface is active during the prelaunch operations (see Figure 5 0 0-1) and during post-landing safing Any post-landing data interfaces in addition to those for prelaunch have not been identified in this study

The Tug/GSE data interfaces (through the Deployment Adapter (D/A)) are for the Tug/SC 16 KPBS link which contains the same C&W, safety related and status data provided to the Orbiter The GSE command/monitor link interface (1 MBPS) provides 2-way communications between the onboard computer and the GSE (through the D/A) and provides the capability for prelaunch operations, updates or status required prior to liftoff

5 5 TUG/DEPLOYMENT ADAPTER INTERFACE

Telemetry and command/monitor data links exist between the Tug and the Tug Deployment Adapter as shown in Figure 5 0 0-1 These links are routed from the Tug Computer Interface Unit (CIU) to the D/A MUX/DEMUX which routes data to the Orbiter and the GSE The functional interface between the Tug and D/A is two commands from the Tug to the D/A for use during abort The Tug and Tug D/A separate during deployment and are reattached during Tug retrieval operations

5 6 TUG/INTERSTAGE ADAPTER INTERFACE

The Tug/Interstage Adapter interfaces are shown in Figures 5 0 0-1 and 5 0 0-2 These interfaces are to provide separation/pyrotechnic commands to the separation devices and to monitor their status The capability also exists to excite the adapter instrumentation transducers and to monitor the corresponding results and status This interface is active during the Tug/SC separation phase

SPACE TUG DEPLOYMENT AND RETRIEVAL OPERATIONS 6

The major emphasis in the area of Tug deploy and retrieval operations was to develop the Tug on-orbit checkout requirements This was done by first developing a checkout (C/O) philosophy and then implementing if found consistent with the Tug checkout requirements and design

6.1 ANALYSIS OVERVIEW

An overview of the Space Tug orbital checkout analysis is shown in Figure 6 1 0-1

6.1.1 Study Purpose and Flow

The purpose of this analysis is to develop a C/O philosophy consistent with hardware design trends and requirements The philosophy is also influenced by goals which tended to maintain analysis direction With a defined philosophy it was possible to develop a checkout/monitoring summary which defines what and when, and is, in effect, a timeline The checkout functions are then assigned to establish prime and backup responsibility Finally, the C/O software resident in the Orbiter was sized to provide an estimate of the impact to the Orbiter subsystems

6 1 2 Definitions of Orbital Checkout Terms

The orbital checkout analysis required the development of a definition of certain terms because of their varied usage A summary of the definition of orbital C/O terms is contained in Table 6 1 2-1 The following is a description of the most ambiguous terms

- Status Monitor - This is the routine assessment of the telemetry data to determine system status It is basically limit checking of voltages, temperatures, and pressures

- Checkout - Extraordinary effort taken to determine health or ability to function, such as applying a command or a stimulus and noting the reaction compared to expectations

- Operational Monitor - Monitoring of normal operational system output to be compared to normal timeline operational system data to assess system health

- Activation Monitor - Monitoring of parameters which indicate proper turn-on to the best step by step detail that existing telemetry measurements will allow

- Prime Responsibility - This is the designated origin of test or health inquiry per operational timeline and the designated evaluator of results

- Back-Up Responsibility - This is the designated back-up who monitors test or health inquiry per operational timeline and reports results as a back-up or check Back-up commanding of the test may be done also as a contingency.

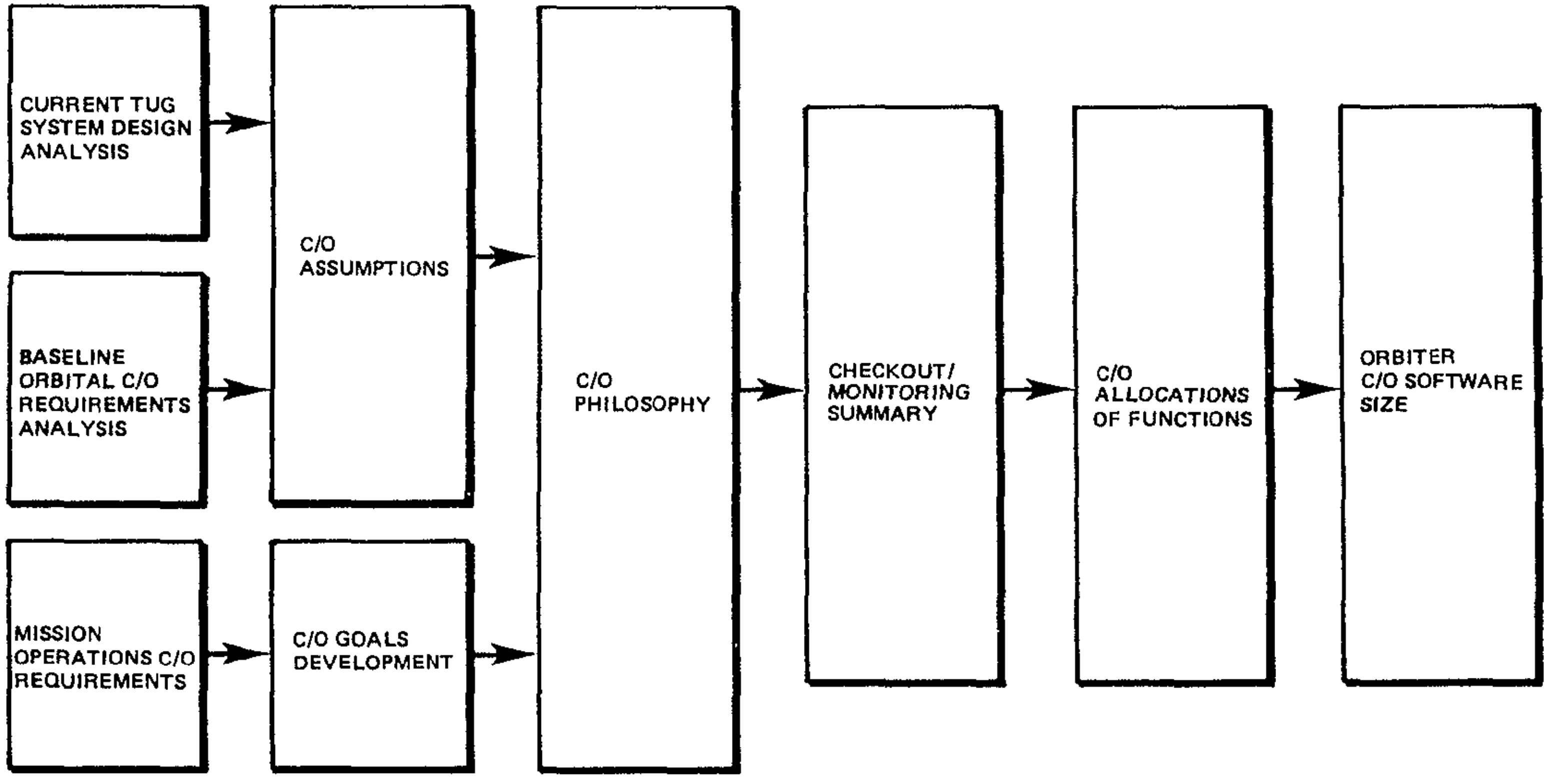


Figure 6 1 0-1 Space Tug Orbital Checkout Analysis

Table 6 1 2-1 Summary of Definitions of Orbital Checkout Terms

1 STATUS MONITOR - ROUTINE ASSESSMENT OF TM STREAM TO DETERMINE HEALTH

2. CHECKOUT - EXCEPTIONAL EFFORT TO DETERMINE HEALTH OR ABILITY, I E., STIMULUS RESPONSE.

3. OPERATIONAL MONITOR - MONITOR OPERATIONAL RESULTS DURING NORMAL UP TIMES -- DYNAMIC MEAS.

4 ACTIVATION MONITOR - MONITOR RESULTING TM FROM TURN-ON PROCEDURES

5 DEACTIVATION MONITOR - MONITOR RESULTING TM FROM TURN-OFF PROCEDURES

6 PRIME RESPONSIBILITY - INITIATES TEST OR HEALTH INQUIRY PER TIMELINE AND REPORTS RESULTS.

7 BACK-UP RESPONSIBILITY - MONITORS TEST OR HEALTH INQUIRY AND REPORTS RESULTS AS A BACK-UP

8 DYNAMIC TESTING - TESTING/MONITORING DONE IN EVENT OF FAILURE DETECTION

9 BITE - BUILT IN TEST EQUIPMENT

10 PRE-DEPLOY STATUS/CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO ENABLE COMMIT TUG TO DEPLOY

11 POST-DEPLOY CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO ENABLE COMMIT TUG TO MISSION

12. PRE-RETRIEVAL CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO ENABLE COMMIT TUG TO RETRIEVAL.

13 POST-RETRIEVAL CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO ENABLE COMMIT TO DEORBIT WITH SAFE TUG

6 2 REQUIREMENTS, GROUNDRULES AND ASSUMPTIONS

The requirements, groundrules and assumptions are defined to clarify the basis for this analysis

6.2 1 Space Tug Orbital Checkout Requirements Assessment Summary

This is a summary of the Space Tug orbital checkout baseline requirements assessment, contains results of their assessment, and incorporates actions resulting from data exchange meetings

The requirements are categorized into two main areas implemented and exceptions The category of implemented is further divided or allocated into area of responsibility. The implemented and allocated requirements are those where there is agreement and therefore are being utilized as a basis for Space Tug orbital checkout The category of exceptions consists of those requirements where there is not agreement and exception is being taken Rationale is given for the exception

6 2 1 1 Baseline Operational Requirements Implemented and Allocated

The following requirements are those where there is agreement and therefore are being implemented They are allocated to prime and back-up responsibilities to enable specific definitions and sizing of operational impact.

- Shuttle Prime Responsibilities
  - Shuttle will monitor Tug/Spacecraft systems during all flight phases while in cargo bay
  - Shuttle will hold Tug APS inhibited till after release by RMS. Shuttle will enable Tug APS
  - Shuttle will disable Tug APS prior to retrieval or for mission termination
  - Shuttle will monitor Tug/SC crew safety related parameters during near vicinity operations
  - For mission abort, crew will initiate and monitor Tug propellant dump prior to Tug release
  - Shuttle will monitor Tug/SC systems to ensure safe condition through landing
- Shuttle Back-Up Responsibilities
  - Shuttle crew will support (upon ground request) pre-deploy C/O
- Ground Control Prime Responsbilities
  - Ground controllers will verify readiness of Tug/SC for deploy based on monitoring Tug/SC systems

- Ground controllers will verify readiness of Tug/SC for retrieval based on monitoring Tug/SC systems

- Ground controllers will maintain detailed status of Tug/SC systems for entire mission

- Ground Control Back-Up Responsibilities

  - Ground control will provide back-up control of crew safety functions

- Tug Prime Responsibilities

  - Redundancy management will be done by Tug

  - Thru-put checkout results from SC

6 2 1 2 Baseline Operational Requirements Exceptions

The Space Tug orbital checkout baseline requirements were reviewed to determine any potential requirements conflicts with projected design or operations philosophies The exceptions are as noted with rationale given for each

- Requirement Excerpt From Baseline Flight Operations, Volume 3, Paragraph 3 6 1

  Tug/Spacecraft Monitoring and Checkout by the Shuttle

  "The Shuttle must checkout and activate the Tug attitude hold systems prior to remote manipulator system (RMS) release, and inhibit the APS until after release is accomplished "

  Rationale - APS will not be checked out prior to use, system consists of series of valves which will be status monitored when used

- Requirement Excerpt From Baseline Flight Operations, Volume 3, Paragraph 4 3 1 4

  Tug/SC Deploy

  "They will then remove the Tug/SC from the bay and deploy it to the release position Then under control of the crew and monitored by the crew and the ground, the Tug will be prepared for release After ground acquisition of Tug signal, and upon receiving affirmation of correct configuration from the ground, the crew will release the Tug and stow the manipulator(s) "

  Rationale - Ground acquisition of Tug signal before release from RMS will not be affirmed Deploy lighting, antenna pointing and Orbiter interface constraints make exception necessary

6 2.2 Groundrules and Assumptions

The following groundrules and assumptions were made to bound the analysis and to capture key baseline requirements and Tug design features that heavily influenced the task

Tug Checkout Analysis Groundrules and Assumptions

- The baseline Tug is required to be reusable.
- The baseline Tug is Level II Autonomy
- The current Tug avionics definitions show BITE is available on Tug
- The current Tug avionics is redundant and therefore contains redundancy management
- The baseline Tug is operational in the vicinity of the manned Orbiter
- The analysis includes pre and post deployment and retrieval check-out, because of concern with Orbiter/Tug operational relationships.

6 3 SPACE TUG REDUNDANCY AND SELF-TEST SUMMARY

The fact that Space Tug is designed as basically a redundant system and as baselined Level II autonomy it must provide BITE The redundancy level was investigated and also self-test capability

6 3 1 Tug Operational Redundancy Summary

Table 6 3 1-1 gives a summary of the major Tug components (or subsystems), the redundancy level of the components, any backup capability available, and the function of the component

As shown by the asterisks most Tug components are critical for mission success, and all critical system are redundant. Redundancy management is available onboard consistent with baseline autonomy Level II Contingency work-around will be possible Orbital operations will take full advantage of available redundancy and redundancy management

6 3 2 Space Tug Sensor Checkout Capability Summary

Table 6 3.2-1 shows that with redundancy management software utilizing the checkout capability that exists for the Tug components/subsystems the Tug will be largely autonomous. The Orbiter will be involved mainly in safety related status and contingency back-up The ground will be involved mainly in status keeping and as contingency back-up The systems mandatory for Tug operation are noted with asterisks

6.4 CHECKOUT GOALS AND PHILOSOPHY

The Space Tug on-orbit checkout goals are direct results of application of mission operation goals to this particular problem The Space Tug on-orbit

Table 6 3 1-1 Tug Operational Redundancy Summary

COMPONENT/SUBSYSTEM	REDUNDANCY	BACKUP	FUNCTION
*IMU	2 Failures Tolerant	--	Inertial Reference (with DMS)
Rate Gyros	2 Failures Tolerant	--	Flight Control Aid
ILT	1 Channel	Ground	Navigation Update
Star Trackers Sun Sensors	1 Spare Each	--	Attitude Update
*DMS	Dual Redundant	--	On-Board Processing and Control
*Fuel Cells	Dual Redundant	Batt	Power Generation
Laser Radar	--	Ground, LLLTV	Rendezvous with Payload
**LLLTV	Dual Redundant	--	Docking with Payload
Communications	Dual Redundant	--	Orbiter, Ground Interface
*Auxiliary Propulsion System	Basically Redundant	--	Attitude Control, Low Level Thrust
*Main Propulsion System	Some Simplex Some Redundant	--	High Energy Thrust

*Systems Mandatory for Tug Operation
**LLLTV Mandatory for Tug Docking with Payloads

Table 6 3 2-1 Tug Sensor Checkout Capability Summary

COMPONENT/SUBSYSTEM	CHECKOUT CAPABILITY
STAR TRACKER	LIGHT SOURCE FOR SELF-TEST
SUN SENSOR	LIGHT SOURCE FOR SELF-TEST
ILT	INJECTED RF SIGNAL FOR CLOSED LOOP VERIFICATION
*DMS	INTERNAL SELF-TEST CAPABILITY
*FUEL CELLS	BITE-CONTINUOUS
SIGNAL CONDITIONERS	LIMITED A/D CONVERTER CHECKS
*ENGINE CONTROL ELECTRONICS	FULL END-TO-END CHECKOUT CAPABILITY
*IMU	PARTIAL CHECKOUT CAPABILITY - QUICK LOOK

*SYSTEMS MANDATORY FOR TUG OPERATION

checkout philosophy, summarizes all of the requirements into a workable set of rules which allow systematic addressing of the problem

6 4 1 Space Tug On-Orbit Checkout Goals

The goals used in this analysis are contained in Table 6 4 1 1

6 4 2 On-Orbit Checkout Philosophy

The major emphasis on Tug on-orbit checkout is to utilize Tug status, activation and operational data, rather than interactive checkout results, to determine Tug subsystem status

Some components are activated throughout the mission, while others may not be required for all mission phases To conserve power and enhance reliability, subsystems and components activated after deployment should be checked out then Since the Tug is basically autonomous, sequences will be initiated and controlled by the Tug where possible No nominal mission command activity is allocated to the ground and only safety related Orbiter involvement is required after deployment

The ground will monitor all telemetry data generated by the Tug for status decisions and will provide commands or inhibits only if onboard malfunctions occur It will report safety related impacts to the Orbiter crew

The Orbiter will monitor and control safety related and critical subsystem parameters and will initiate some activation and deactivation sequences during critical phases, such as deployment and retrieval. It will provide backup capability to the ground for selected Tug subsystems

The Tug will initiate and control all Tug sequencing and functions which do not directly impact the health or safety of the Orbiter and its crew

The major items in the Space Tug on-orbit checkout philosophy are contained in Table 6 4 2-1

6 5 PRE-DEPLOY CHECKOUT OPERATIONS

The purpose of pre-deploy checkout operations is clearly stated by the following definition

> PRE-DEPLOY STATUS/CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO ENABLE COMMIT TUG TO DEPLOY

6 5 1 Pre-Deploy Component Activations

Table 6 5 1-1 shows the activation/deactivation sequence recommended for Tug operations As shown the DMS is the only element active throughout the mission This is necessary for status keeping telemetry. The IMU and communications are necessary just after deployment, therefore, should be activated when required

Table 6 4 1-1 Space Tug On-Orbit Checkout Goals

- PROVIDE OPERATIONAL VERIFICATION OF TUG PRIOR TO MAJOR EVENTS
- MAINTAIN STATUS OF ALL TUG SUBSYSTEMS
- MINIMIZE ORBITER INVOLVEMENT
- COST EFFECTIVE UTILIZATION OF GROUND
- MINIMIZE POTENTIAL ORBITER SAFETY IMPACTS
- PROVIDE COST EFFECTIVE APPROACHES FOR ON-BOARD CHECKOUT
- EFFECTIVE USE OF TUG ON-BOARD CAPABILITIES TO SUPPORT CHECKOUT AND REDUNDANCY MANAGEMENT
- MINIMIZE MISSION TIMELINE POTENTIAL IMPACTS

Table 6 4 2-1 Space Tug On-Orbit Checkout Philosophy

- UTILIZE TUG STATUS, ACTIVATION/DEACTIVATION AND OPERATIONAL DATA FOR TUG SUBSYSTEMS HEALTH
- TUG COMPONENTS/SUBSYSTEMS ARE NOT ACTIVATED UNTIL REQUIRED FOR OPERATION
- NO PREPLANNED COMMAND ACTIVITY ALLOCATED TO GROUND CONTROL (CONTINGENCY ONLY)
- NO ORBITER CHECKOUT INVOLVEMENT AFTER DEPLOYMENT AND PRIOR TO RETRIEVAL
- GROUND INVOLVEMENT
  - MONITORS STATUS, ACTIVATION/DEACTIVATION, CHECKOUT AND OPERATIONAL DATA
  - PROVIDES COMMANDS OR INHIBITS IF ONBOARD TUG MALFUNCTIONS OCCUR
- ORBITER INVOLVEMENT
  - MONITORS C&W, SAFETY AND CRITICAL SUBSYSTEM PARAMETERS
  - CONTROLS DEPLOYMENT AND RETRIEVAL OPERATIONS
  - INITIATE SOME ACTIVATION/DEACTIVATION AND BACKUP SEQUENCE INITIATION COMMANDS
- TUG COMMANDS ALL NON-C&W/ABORT TUG SEQUENCING

Table 6 5.1-1. Tug Major Component Activation/Deactivation Sequence

	DEPLOYMENT		RETRIEVAL	
COMPONENT/SUBSYSTEM	PRE-DEPLOY	POST-DEPLOY	PRE-RETRIEVAL	POST-RETRIEVAL
DMS	X	X	X	X
IMU	ACTIVATE	X	X	DEACTIVATE
ELECTRICAL POWER	X	X	X	DEACTIVATE
COMMUNICATIONS	ACTIVATE	X	X	DEACTIVATE
APS		ACTIVATE	DEACTIVATE	
MAIN PROPULSION		ACTIVATE	DEACTIVATE	
GN&C UPDATE SENSORS		ACTIVATE	DEACTIVATE	
RENDOCK SENSORS		ACTIVATE	DEACTIVATE	

X = PREVIOUSLY ACTIVATED

6 5 2 Pre-Deployment Flight Operations Functional Allocation

Table 6 5 2-1 shows the major flight operations activities to be performed for the Tug pre-deployment and the allocation of functions, either prime (X) or backup (B/U) The functions include the on-orbit operations prior to deployment

During the pre-deployment phase, the Orbiter is prime for safety related functions and for functions related directly to deployment Therefore, as shown, most activities during the deployment phase are controlled by the Orbiter

As shown, the Tug is prime for IMU activation and sequencing which would not affect the crew safety, while the ground is prime only for monitoring functions The ground is also backup for contingency operations

6 5 3 Checkout/Monitoring Summary

Table 6 5 3-1 indicates the primary types of data gathered for Tug status evaluation for the various mission phases As shown, status and operational data are the primary means for health determination when the components are active

For components which are activated on orbit, limited status data (either measurement or lack of measurement) is available prior to being activated, activation data is available during component turn-on, and operational data available after activation

The Tug IMU and Orbiter state vectors will be compared after initialization to determine if Tug navigation and attitude updates are required. The proper operation and maneuvers by the Orbiter will verify that system

The only candidate for checkout is the IMU and main propulsion system. The IMU is only capable of partial checkout however, so quick look techniques will be used Although operational status is mainly verified by proper main engine operation, some engine gimballing or valve sequencing is available for limited checkout

6 6 POST-DEPLOY CHECKOUT OPERATIONS

The purpose of the post-deploy checkout operations is clearly stated in the following definition

> POST-DEPLOY CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO COMMIT THE TUG TO MISSION

6 6 1 Post-Deploy Component Activation

Table 6 5 1-1 shows the activation/deactivation sequence recommended for Tug operations As is shown for post-deploy, the Attitude Propulsion System (APS) cannot be activated, for Orbiter safety reasons, until immediately after deployment The main propulsion will be activated after the Orbiter is a safe distance from the Tug

Table 6 5 2-1 Tug Flight Operations Functional Allocation (Pre-Deploy)

	ALLOCATION		
FUNCTION	TUG	ORBITER	GROUND
C&W/SAFETY MONITORING/CONTROL		X	B/U
TUG STATUS MONITORING		B/U	X
VENTS, PURGES	X	B/U_1	B/U_2
IMU ACTIVATION	X	B/U	
IMU INITIALIZATION, CHECKOUT		X	B/U
NAVIGATION, ATTITUDE UPDATES		X	B/U
DEPLOYMENT ADAPTER OPERATIONS		X	
RMS OPERATIONS		X	
POWER TRANSFER		X	
COMMUNICATIONS ACTIVATION		X	
ORBITER/TUG RF VERIFICATION		X	

PRIME = X
BACKUP NO 1 = B/U_1
BACKUP NO. 2 = B/U_2

Table 6 5 3-1 Tug Major Component Checkout/Monitoring Summary

	DEPLOYMENT		RETRIEVAL	
COMPONENT/SUBSYSTEM	PRE-DEPLOY	POST-DEPLOY	PRE-RETRIEVAL	POST-RETRIEVAL
DMS	S,O	S,O	S,O	S,O
IMU	S,O,A,C	S,O	S,O	S,D
ELECTRICAL POWER	S,O	S,O	S,O	S,D
COMMUNICATIONS	S,O,A	S,O	S,O	S,D
APS	S	S,O,A	S,O,D	S
MAIN PROPULSION	S	S,O,A,C	S,O,D	
GN&C UPDATE SENSORS	S	S,O,A	S,O,D	
RENDOCK SENSORS	S	S,O,A	S,O,D	

S - STATUS MONITORING
O - OPERATIONAL MONITORING
A - ACTIVATION MONITORING
C - CHECKOUT
D - DEACTIVATION MONITORING

The GN&C update sensor will be activated prior to the first main propulsion burn to receive a navigation update. The rendezvous and docking sensors will be activated prior to the rendezvous and docking phase of the mission

6 6 2 Post-Deploy Flight Operations Functional Allocation

Table 6 6 2-1 shows the major flight operations activities to be performed for the Tug post-deployment and the allocation of functions, either prime (X) or backup (B/U). The functions include the on-orbit operations after Tug deployment

During the post-deploy phase, the Orbiter is prime for safety related functions and for functions related directly to deployment Therefore, as shown, most activities during the deployment phase are controlled by the Orbiter.

The Tug is prime for APS final activation and MPS activation and sequencing which would not affect the crew safety, while the ground is prime only for monitoring functions The ground is also backup for contingency operations

6 7 PRE-RETRIEVAL CHECKOUT OPERATIONS

The purpose of pre-retrieval checkout operations is clearly stated by the following definition

> PRE-RETRIEVAL CHECKOUT-TUG STATUS/CHECKOUT REPORTING TO COMMIT THE TUG TO RETRIEVAL

6 7 1 Pre-Retrieval Component Deactivation

Table 6 5 1-1 shows the deactivation sequence recommended for Tug operations Deactivation will occur soon after concluding use to conserve operating life and power APS is deactivated just prior to retrieval because it is required to maintain a stable attitude

6 7 2 Pre-Retrieval Flight Operations Functional Allocation

Table 6 7 2-1 shows the major flight operations activities to be performed for the Tug retrieval and the allocation of functions, either prime (X) or backup (B/U) The functions include the on orbit operations prior to the Tug retrieval

As shown, the Tug is prime for certain deactivation and sequencing which would not affect the crew safety, while the ground is prime only for monitoring functions The ground is also backup for contingency operations

During the retrieval phase, the Orbiter is prime for safety related functions and for functions related directly to retrieval Therefore, most activities during the retrieval phase are controlled or backed up by the Orbiter For pre-retrieval however, the Tug is prime while generally post-retrieval the Orbiter is prime

Table 6 6.2-1 Tug Flight Operations Functional Allocation (Post-Deploy)

	ALLOCATION		
FUNCTION	TUG	ORBITER	GROUND
APS INITIAL ACTIVATION		X	B/U
C&W/SAFETY MONITOR/CONTROL		X	B/U
TUG STATUS		B/U	X
APS FINAL ACTIVATION	X	B/U_2	B/U_1
MPS ACTIVATION, CHECKOUT	X		B/U

PRIME = X
BACKUP NO 1 = B/U_1
BACKUP NO 2 = B/U_2

Table 6 7 2-1 Tug Flight Operations Functional Allocation (Retrieval)

	ALLOCATION		
PRE-RETRIEVAL	TUG	ORBITER	GROUND
TUG STATUS MONITORING		B/U	X
C&W/SAFETY MONITOR/CONTROL		X	B/U
MPS DEACTIVATION/SAFING	X	B/U_2	B/U_1
GN&C SENSOR DEACTIVATION	X		B/U
PROPELLANT DUMP	X	B/U_2	B/U_1
ACS INITIAL INHIBIT	X	B/U_2	B/U_1
POST-RETRIEVAL			
C&W/SAFETY MONITOR/CONTROL		X	B/U
TUG STATUS MONITOR		B/U	X
ACS FINAL INHIBIT/DEACTIVATION		X	
COMMUNICATIONS DEACTIVATION		X	
POWER SWITCHING		X	
FUEL CELL DEACTIVATION	X	B/U	
IMU DEACTIVATION	X	B/U	

PRIME = X
BACKUP NO 1 = B/U_1
BACKUP NO 2 = B/U_2

6 8 POST-RETRIEVAL CHECKOUT OPERATIONS

The purpose of post-retrieval checkout operations is clearly stated by the following definition

> POST-RETRIEVAL CHECKOUT - TUG STATUS/CHECKOUT REPORTING TO COMMIT TO DEORBIT WITH A SAFE TUG

6 8 1 Post-Retrieval Component Deactivation

Table 6 5 1-1 shows the deactivation sequence recommended for Tug operations Deactivation will occur soon after concluding use to conserve operating life DMS remains on for status keeping telemetry generation

6 8 2 Post-Retrieval Flight Operations Functional Allocation

This is covered by the text of 6 7 2 Pre-Retrieval Flight Operations Functional Allocation and the lower portion of Table 6 7 2-1

6 9 ORBITER IMPACTS SUMMARY

An assessment of the Orbiter impacts based on the results of the Tug deployment and retrieval operations was made to determine if potential Orbiter support problems exists. This section presents a discussion of the Orbiter operational support functions for the Tug which would impact Orbiter software and a computer/software sizing estimate to support those functions

6 9 1 Operations Support Functional Description

The Orbiter functions required to support the Tug on-orbit flight operations are summarized in Table 6 9 1-1 Since the Orbiter is required to monitor selected Tug safety and status parameters, the Orbiter must process the Tug telemetry data stream to the Orbiter (16KPBS) and retrieve the data parameters required for analysis After the correct C&W, safety and status parameters are selected, the Orbiter will compare those parameters with the expected results or limits and store the data for future display by the Orbiter C&D as required

The Orbiter will also monitor the operational status of all Tug mission critical components as a basis for operational impacts Any anomalies detected by the Orbiter will be evaluated and, if necessary, corrective command action will be taken to alleviate the anomaly

The Orbiter is also required to initiate or support selected Tug activation, deactivation or operational support sequences while the Tug is attached or in close proximity to the Orbiter These functions include power transfer and deactivation, Tug communications activation and verification and deactivation, APS initial activation and final deactivation, Tug navigation, attitude or target updates, and initialization of the Tug IMU after it is activated on-orbit After initialization, the Orbiter will perform attitude maneuvers to assure the Tug IMU is operating properly by comparing the state vectors State vector updates will be provided if required These support functions are included in the nominal mission timeline

Table 6 9 1-1 Orbiter Software Functions to Support Tug

- SAFETY/STATUS MONITORING
  - TUG TELEMETRY PROCESSING (16 KBPS)
  - C&W/SAFETY PARAMETER MONITORING/CONTROL
  - SELECTED TUG SUBSYSTEM STATUS MONITOR/CONTROL
- TUG INITIALIZATION ACTIVATION AND DEACTIVATION SUPPORT
  - IMU INITIALIZATION, ORBITER MANEUVERS AND STATE VECTOR COMPARISONS
  - POWER TRANSFER/DEACTIVATION
  - NAVIGATION, ATTITUDE AND TIMING UPDATES
  - COMMUNICATIONS ACTIVATION, VERIFICATION AND DEACTIVATION
  - APS INITIAL ACTIVATION AND FINAL DEACTIVATION
- CONTINGENCY SEQUENCING SUPPORT
  - ACTIVATION/DEACTIVATION (APS, MPS, IMU, FUEL CELL)
  - DEACTIVATION (GN&C SENSORS)
  - PROPELLANT DUMP, VENTS AND PURGES
  - ABORT SEQUENCING
- MISCELLANEOUS ORBITER SUPPORT
  - DEPLOYMENT/RETRIEVAL OPERATIONS
  - REMOTE MANIPULATOR OPERATIONS
  - COMMUNICATION SWITCHING/RECORDING MANAGEMENT
  - TUG ATTITUDE-COLLISION AVOIDANCE MONITORING

For the activation and deactivation sequencing, commands would be sent and data received to determine if satisfactory results were obtained. The Tug state vector evaluation would be more complex with the comparisons evaluated, and updates initiated if required

The Orbiter will also provide limited capability to support contingency operations associated with the Tug, such as abort sequencing, subsystem activation and deactivation sequencing, vents and purges These functions would only be required for contingency operations and could either be hardwired or commanded through the RF link Except for abort sequencing, which is a prime Orbiter function, most of the contingency activation/deactivation sequencing is backup to both the Tug and ground

The Orbiter also provides operations support for the Tug when the Tug vehicle or subsystems are not actively involved in the operations Examples of these types of functions include RMS remote manipulator operations, communication switching and recording of Tug telemetry and commands, deployment operations and collision avoidance computations These items may not be charged to the Tug/Spacecraft, but are defined as necessary to support Tug operations

6 9 2 Computer/Software Impacts

The basic Orbiter/Tug on-orbit operations philosophy was to perform as many of the required software functions in the Tug as possible, which would mean that the Orbiter would only initiate sequences which would be performed by the Tug This is especially true for the activation and deactivation sequencing This section reviews the Orbiter software functions sized to support the Tug Functions to support the Spacecraft were not sized.

6 9 2 1 Sizing Summary

A summary of the Orbiter software storage impacts to support the Tug operations are given in Table 6 9 2-1 The functions to be sized were discussed in the previous section, and are divided into two groups, Orbiter interactive support for Tug and Orbiter controlled support for Tug. The interactive support includes the Tug/Orbiter interfaces and operations, Tug safety/status monitoring, Tug subsystem initialization activation, deactivation and operations support, and backup or contingency sequencing support. The Orbiter controlled support includes overhead to the Orbiter operating system (OS) and Tug displays, controls in the MSS, and miscellaneous support provided to the Tug such as remote manipulator, communications and deployment adaptor operations which are done independent of Tug involvement Some of the Orbiter controlled support items may not be charged to the Tug

The sizing assumes that a 75% short and 25% long mix for both instructions and data is used to obtain the total Orbiter storage requirements The Orbiter is baselined with a 32 bit word length for storage. The summary in Table 6 9 2-1 indicates that approximately 16K of 32 bit words is required in the Orbiter DMS, assuming that both interactive support and Orbiter controlled support are charged to the Tug But, since only a portion of the total storage is required at any one time, only about 2 5K of 32 bit words is required in main storage at one time Therefore, the Tug required software can be stored in the Orbiter mass storage and called into main memory when required for

Table 6 9 2-1 Orbiter Software Sizing to Support Tug

	INST	DATA	*TOTAL (32 BIT WORDS)	MAX MAIN MEMORY (32 BIT WORDS)
• INTERACTIVE SUPPORT FOR TUG				
- SAFETY/STATUS MONITORING	350	9,055	5,878	1,031
- INITIALIZATION, ACTIVATION AND DEACTIVATION	2,450	1,030	2,175	938
- CONTINGENCY SEQUENCING SUPPORT	3,800	2,675	4,047	-
SUBTOTALS	6,600	12,760	12,100	1,969
• ORBITER CONTROLLED SUPPORT				
- MSS SUPPORT SOFTWARE (OVERHEAD)	500	350	531	531
- MISCELLANEOUS ORBITER SUPPORT	3,200	2,450	3,532	-
	3,700	2,800	4,063	531

*ASSUME 75% SHORT AND 25% LONG INSTRUCTION AND DATA MIX

operations. The major Orbiter storage impacts are for Tug display formats and data (12 formats assumed) which will be displayed in the Orbiter for safety and status monitoring The functions sized have extremely low execution rates, and when coupled with low instruction numbers, a minimal speed impact to Orbiter is expected The Orbiter support requirements appear to be well within the support capability of 10K main memory and 18 KOPS provided to payloads by the Orbiter, assuming the Tug support programs can be stored in the Orbiter Mass Storage and called into main storage when required.

6 9 2 2 Interactive Support Details

The interactive support sizing details include safety/status monitoring, activations/operations support, contingency sequencing support, and are shown in Tables 6 9 2-2 through -4

The safety/status monitoring support (Table 6 9 2-2) lists the items sized. The 16 KPBS telemetry stream from the Tug is processed by the Orbiter to selected the estimated 100 (of about 200 total Tug) telemetry parameters which would be used by the Orbiter for safety and status monitoring The parameters requiring limit, status, or go/no-go checks are processed by the Orbiter computer for anomaly reporting The Tug data will be grouped into display formats and associated display parameters for use by the MSS personnel. Twelve displays are assumed and the display format (or display background) and the mapping tables, which select the parameters to be displayed on the format, were included in the sizing As shown, the display images (or formats) are the main storage impacts, with a total storage requirement of 4 5K of 32 bit words

The initialization, activation, deactivation and operations sequencing by the Orbiter to support the Tug (Table 6 9 2-3) are the power transfer, ACS initial arming, communications activation and verification, and Tug state vector comparison and update during deployment, and APS deactivation, fuel cell deactivation, and communications deactivation during retrieval The commands are in tables which contain the command address, time of issuance, sequence dependency, verification response from the Tug and error processing indication, if required The GN&C update capability will provide an evaluation of the Tug state vector to determine the need for an update and to provide the updates if required Only about 2 2K are required for these items.

The contingency sequencing support (Table 6 9 2-4) provides backup activation/deactivation or sequencing capability to support the Tug The items sized include a more detailed activation/deactivation sequence than required for normal operations and would be used only if Tug (or ground) operation were not feasible The abort sequencing is controlled only by the Orbiter, but was included in the contingency support since it is not required during normal on-orbit opearations Approximately 4K of storage is required for the contingency sequencing support

6 9 2 3 Orbiter Controlled Support

The functions sized for Orbiter controlled support do not interface with the Tug, but provide support for Tug operations These include MSS support software and miscellaneous Orbiter support The sizing impacts are shown, respectively, in Tables 6 9 2-5 and 6 9 2-6

Table 6 9 2-2. Safety/Status Monitoring Sizing

FUNCTION	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
TELEMETRY STREAM PROCESSING	250	750	625
LIMIT TESTING/STATUS CHECKING	100	25	78
DISPLAY IMAGES (12 IMAGES @ 600 WORDS/DISPLAY)	--	7,200	4,500
DISPLAY MAPPING TABLES (12 IMAGES X [6 WORDS/IMAGE ENTRY X 15 ENTRIES])	--	1,080	675
TOTALS	350	9,055	5,878

Table 6 9.2-3 Initialization, Activation and Deactivation Sizing

FUNCTION(*)	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
POWER TRANSFER	200	70	169
APS ARMING	250	80	206
APS DEACTIVATION	250	80	206
FUEL CELL DEACTIVATION	250	100	219
UPDATE GN&C PARAMETERS	1,000	500	937
COMMUNICATION ACTIVATION/ VERIFICATION	250	100	219
COMMUNICATION DEACTIVATION	250	100	219
			2,175

(*) ONLY ONE FUNCTION IS RESIDENT IN ORBITER MEMORY AT ANY TIME

Table 6 9 2-4 Contingency Sequencing Support

FUNCTION(*)	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
MISSION SEQUENCE START	50	25	47
TUG IMU/DMS INITIALIZATION/ ACTIVATION	500	500	625
FUEL CELL ACTIVATION	200	150	219
APS ACTIVATE	200	150	219
APS DEACTIVATION	200	150	219
MPS ACTIVATION	200	150	219
MPS DEACTIVATION	200	150	219
GN&C COMPONENT ACTIVATION	500	250	268
PROPELLANT DUMP	500	250	468
VENTS/PURGES	500	250	649
ABORT COMMANDING	750	650	875
TOTALS	3,800	2,675	4,047

(*) ONLY ONE FUNCTION OCCUPIES ORBITER COMPUTER MEMORY AT ANY TIME.

Table 6 9 2-5 MSS Support Software (Overhead) Sizing

FUNCTION	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
FUNCTION/PHASE INITIALIZATION	500	100	374
TABLES FOR OS INPUT/OUTPUT UTILIZATION	--	250	156
TOTALS	500	350	531

Table 6 9,2-6 Miscellaneous Orbiter Support Sizing

FUNCTION	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
RMS OPERATIONS	1,000	500	938
TUG ATTITUDE/COLLISION AVOIDANCE	250	150	250
DEPLOYMENT SEQUENCING	750	750	938
UMBILICAL MECHANISMS	500	500	625
CAPTURE LATCHES CONTROL	500	500	625
COMMUNICATIONS MGMT	200	50	156
TOTALS	3,200	2,450	3,532

The MSS support software (Table 6 9 2-5) includes function/phase initialization and tables for the Orbiter computer operating system (OS) input/output utilization The function/phase initialization sizing includes the selection of displays, responses to keyboard entries, priority assignments and loading data from mass storage The I/O table includes items the Orbiter OS must support, such as valid command tables and display linkage tables The Orbiter storage impact is 531 words

The miscellaneous support (Table 6 9.2-6) includes remote manipulator operations, deployment sequencing, Orbiter communications management to support Tug telemetry/commands and collision avoidance computations The storage impact for these items is about 3 5K

SPACECRAFT DEPLOYMENT RENDEZVOUS AND DOCKING OPERATIONS ANALYSIS 7

The primary responsibility of the Space Tug is to deliver a Spacecraft to a desired location or obital condition, and in some instances, to rendezvous and dock with another Spacecraft and retrieve or service Although the Tug will be designed with the capability to provide support to attached Spacecraft, the Spacecraft community desires that minimum operational interfaces exist between the Spacecraft and Tug, except for servicing missions by the Tug Some operational interfaces are planned between the Spacecraft and Tug This section will discuss the deployment of Spacecraft as well as the rendezvous and docking operations associated with retrieval of Spacecraft

7 1 SPACECRAFT DEPLOYMENT

This section discusses predeployment and postdeployment operations

7 1 1 Spacecraft Predeploy Operations

This section discusses the Spacecraft predeploy operations which include the activities from the final Tug mainstage, or trim burn, maneuver until physical separation of the Spacecraft from the Tug

7 1 1 1 Tug Support

The major Tug functions in support of the Spacecraft predeploy operations are to provide an attitude control base for the Spacecraft while it is being activated and checked out, to provide activation and separation sequencing support and, in some cases, to provide the communication link interface with the ground The Tug may also provide the capability of monitoring Spacecraft status and providing aid to correct the malfunctions

During the phases when the Spacecraft is being ferried from low earth orbit to its final destination, the Spacecraft may provide its own RF communications links with the ground For some payloads, however, the Spacecraft RF communication links will be covered or partially covered by shrouds, payload adapters, other Spacecraft, appendages, etc , and, for those cases, Spacecraft telemetry will be integrated with the Tug RF communications for relay to the ground The command uplink for the Spacecraft will also be relayed through the Tug During the Spacecraft predeploy operations, the ground interface would be through the Tug until the Spacecraft antennas were uncovered on until separation of the Spacecraft In some cases, the ground will use the Tug command interface with the Spacecraft through the forward DIU to execute selected functions initiated by the Spacecraft Operations Center (SOC)

The Tug provides an attitude control base for the Spacecraft during the predeploy operations The Tug will maintain attitude control for both the Tug and Spacecraft until they are separated This allows the Spacecraft to be activated, its appendages extended, and the attitude control and RF ground interfaces to be verified prior to separation If Spacecraft anomalies occur, the Tug can maintain the attitude base for a limited time until work-around corrective action can be taken by the ground

The Tug is expected to provide direct support to Spacecraft, and these services will be optimized or minimized to the extent possible The two main Tug support functions are Spacecraft activation sequencing and Spacecraft orientation and spin-up, if required The activation sequencing may be initiated or performed by the ground, however, the Tug will provide sequencing interface capability, through the forward DIU from the Tug computer, for such as shroud deployment, antenna deployment, solar array deployment, and power activation. If required, the Tug will provide the operation base for the orientation and spin-up of a Spacecraft prior to separation. The Tug may also monitor critical Spacecraft parameters and react to anomaly situations, although this capability is not particularly desired by the Spacecraft community Since the Tug is a reusable vehicle, the Tug would be capable of jettisoning an inoperative or potentially hazardous Spacecraft if it had the potential to destroy the Tug Therefore, the monitoring of Spacecraft potentially hazardous conditions by the Tug is desirable

Prior to final release of the Spacecraft by the Tug, a retrieval assurance checkout would be made to assure an immediate or later retrieval of the Spacecraft is possible A typical checkout list is as follows, with items necessary for retrieval indicated by an asterik.

- Verify deployment of appendages
- Verify payload orientation and stability
- Check payload uplink and downlink transmission to ground
- Check telemetry transmission by payload
- Verify readiness for separation
- Check payload on internal power
- Check retrieval kit items

  *Retrieval battery readiness (nonactivated)
  *Laser operation (Tug equipment)
  *Transponder operation

- *Check Tug TV for docking observation capability

These checks would be made with a combination of both ground and Tug support.

7 1 1 2 Ground Support

Both the Spacecraft Operations Center (SOC) and the Tug Operations Center (TOC) will actively participate in monitoring and controlling vehicle operations during the predeploy operations

The TOC will be primarily responsible for monitoring the Tug status and operations to assure no operational or anomaly impacts which could endanger the Spacecraft The emphasis will be on critical subsystem status and hazardous situation, such as tank over pressurization There will be extensive interface between the SOC and the TOC during this phase for status information, for

attitude and operations potential conflicts, and to assure the correct procedures are executed in the proper sequence

The SOC will have the primary responsibility for Spacecraft activation and operational verification. It will use Spacecraft telemetry and selected event input from the Tug via the TOC to determine if the Spacecraft is ready for separation and if all Spacecraft functions are operational In the event of a malfunction, the SOC will actively command and control the Spacecraft to eliminate the problem Any interaction requests for the Tug will be relayed through the TOC with appropriate feedback to the SOC

7 1 2 Spacecraft Post-Deploy Operations

This section discussed the Spacecraft deployment operation following separation of the Spacecraft from the Tug until the Tug is a safe distance from the Spacecraft

7 1 2 1 Tug Support

After the Spacecraft separates from the Tug, the Tug will maneuver a short distance from the Spacecraft to avoid recontact and potential Spacecraft contamination and will provide for TV inspection of the Spacecraft and also for reattachment capability if required The Tug will have no RF link interface capability with the Spacecraft, so all interface will be controlled by the TOC and/or the SOC The primary emphasis of the inspection will be on assuring that no damage has been done to the Spacecraft and that all appendages are properly deployed

After the inspection, and if reattachment is not required, the Tug will maneuver for its deorbit, subsequent Spacecraft placement, or rendezvous orbit and proceed with its mission

7.1 2 2 Ground Support

After separation, the SOC has the prime responsibility for the Spacecraft, while the Tug has the responsibility to assure evasive maneuvers have been performed correctly and to command and monitor Tug maneuvers for visual inspection of the Spacecraft Unless the SOC provides requirements for maneuvers to inspect particular functions of the Spacecraft, a preprogrammed sequence of maneuvers will be performed by the Tug to allow visual inspection of the Spacecraft If reattachment is required, the request will be made by the SOC to the TOC, and the TOC will initiate the required command sequence to accomplish docking Another primary interaction between the ground centers is required to avoid recontact or contamination of the Spacecraft and to identify any Tug or Spacecraft problems which could jeopardize or potentially impact the respective missions The TOC will react to any potential Spacecraft hazard to the Tug to assure Tug safety When the Tug is a safe distance from the Spacecraft, ground center interface is no longer required

The SOC will monitor the Spacecraft status and perform any required activation, checkout operational monitoring, and commanding. The SOC will also react to any potential Tug impacts on the Spacecraft should they occur

7 2 RENDEZVOUS AND DOCKING OPERATIONS

This special emphasis task was intended to describe a general rendezvous and docking operational flow and to employ that flow description in developing implemental relations for evaluating subsystem constraints and budgets. The method involved the review and assessment of proceding study results Shuttle Sortie Payload Descriptions, Automated Payloads, Level A and Level B volumes, and a logical assessment of the operational sequences required. Following the description of a general functional requirement, the flow was segregated into operational modules and submodules so that each contained complementary and distinct functions

These functional modules were defined so that characteristic parameters could be identified The intermodular relations of the parameters were described in cases where meaningful relations could be derived in a timely manner The goal of parameterization was the identification of these relations in the operational flow so that subsystem constraints and budgets could be quantified and prioritized for mission planning

This report section describes the rendezvous and docking modules, submodules and functions as defined during the study A set of parameters is identified and the relations between some of the parameters are presented Emphasis was placed on those parameters meaningful to rendezvous. Other meaninful parametric relations, particularly those involving translational control in the docking module were not analyzed because of lack of a six-degree-of-freedom Tug simulation including a propellant slosh model.

Before delving into parameters and the rationale for selection, one should understand the operational flow and some of the reasons for its nature. The rendezvous and docking modules are described with the respective submodules of each in the following paragraphs Only the nominal flow is addressed in these paragraphs Some ideas regarding autonomy levels and alternate paths for abnormal operation are presented in Section 7 2 3

7 2 1 Rendezvous Operations

The rendezvous module contains submodules named Rendezvous Acquisition, Terminal Phase Initiation (TPI), and Terminal Phase Transfer (TPT) Rendezvous Acquisition is primarily the detection of the target Spacecraft and initiation of rendezvous procedures Terminal Phase Initiation is the establishing of the desired rendezvous trajectory This trajectory, together with trajectory trim burns and braking burns, is the Terminal Phase Transfer submodule

This rendezvous sequence was based upon the presumption that rendezvous will begin with Tug on a stable orbit coelliptic to that of the Target and a constant differential height above or below the Target The submodule definitions are intended to be sufficiently broad, however, to be meaningful in the case when Tug is being flown on a quite different trajectory, such as a direct ascent.

Having one rendezvous method rather than several will enhance vehicle and ground software reliability and configuration control Flight control personnel will be able to establish and learn one set of cues for use in monitoring the flow

7 2 1 1 Rendezvous Acquisition

This submodule comprises the pointing of the rendezvous tracker during search, the initial acquisition and tracking of the target Spacecraft, or Target, and the adjustment or updating of the Tug state vector (Figure 7 2 1-1)

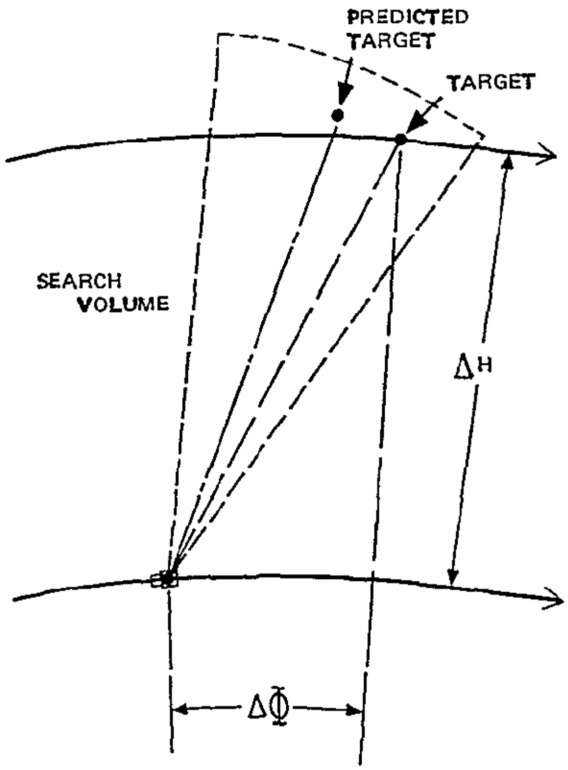


Figure 7 2 1-1 Rendezvous Acquisition

Rendezvous Acquisition begins with the Tug on a nominally constant-differential-height (CDH) orbit coplanar and coelliptic to the Target orbit The altitude difference (ΔH) and central angle differences (ΔΦ) between Tug and Target result from the targetting of prior burns and from the positional dispersions of the two crafts, targetting will be selected to prevent the crafts endangering one another and to place the Tug in a favorable geometry for rendezvous initiation The latter is defined as being either below and behind or above and ahead of the Target so that orbital motion will tend to aid rendezvous rather than hinder it

The rendezvous tracker search pattern will be based upon the best estimate of Target state provided by the Spacecraft Operational Center

The post-acquisition tracker data will be employed along with Tug state data to yield an updated Tug state vector This state vector will be compared with the present value for reasonableness and, if so found, the Tug state expression will be updated to reflect the tracker data Should acquisition and initial tracking require tracker operation at ranges near the tracker specified maximum capability, so that error can be introduced, this possibility will be flagged for use in tracking reasonableness tests following TPI

The functional sequence defined for Rendezvous Acquisition, as well as for all the other operational submodules, is independent of the implementation scheme For example, the rendezvous tracker can be the same device as the docking tracker but the function during rendezvous is different than that during docking In rendezvous, the target is treated as a point located at some range and angle from the Tug. In docking, knowledge of Target relative attitude is also required

Another example of differences in function implementation is in the initial condition for Rendezvous Acquisition The Tug need not be on a CDH orbit upon initialization of Acquisition, the only requirement is that it be in approximately the same position previously described, i e , below and behind or above and ahead The basic difference in the implementation of the operational flow would occur in the TPI module in that the main engine burn and Tug attitude would compensate for the velocity differences as well as initiating the Lambert closure Relatively high closing velocities at Acquisition may require long-range tracking so that the burn can be accomplished without endangering the Tug or Target

7 2 1 2 Terminal Phase Initiation

This module contains the targetting calculations and the main-engine burn which establishes the transfer trajectory The targetting will generally comprise the definition of a Lambert transfer

The central angle between the Tug and the Target at the time of entry into the TPI submodule will define the type of Lambert transfer optimal, sub-optimal or inadvisable, which will be discussed as an abnormal case Optimal Lambert transfers have predictable best central angles for TPI as illustrated in subsequent parametric relations. If the measured central angle is greater than any in the range of optimal central angles for the measured differential height (ΔH), then the TPI initiation time and the transfer arc length are scheduled for optimality and constrained by variables and parametric relations as discussed in Section 7.2 4

Otherwise, the targetting calculations will attempt to identify non-optimal transfers attainable from the measured Tug state with a TPF impulse requirement within the budget constraint If a non-optimal transfer is possible, the TPI module will be executed without delay

The problem of defining non-optimal transfers is understandably related to initial conditions and is not bounded as well as that for optimal transfer solutions

Non-optimal transfers are those which require more than the minimum amount of impulse for the given differential height and transfer angle. An

optimal transfer must be initiated at a certain central angle relative to the target, but a non-optimal transfer is not so constrained and, thus, may be initiated at relative central angles smaller than that for the optimal case Impulse requirements may not increase at a significantly high rate as the initial central angle deviates from the optimal value, but the parametric relation was not analyzed because of a lack of time Non-optimal transfers may require significantly shorter tracker acquisition ranges than those for the optimal without significantly increasing impulse requirements Definition and analysis of the parametric relation between initial central angle and the impulse requirements at TPI and TPF should proceed as soon as possible.

As the initial range between the vehicles is lessened, the problem of transferring along an orbit degenerates to a problem of closing along the line-of-sight between the vehicles because the conic parameter differences become insignificant The measure of insignificance and a best boundary range, defining whether conic rendezvous is required, were not identified Several simulation cases indicated that ranges of at least five nautical miles can be negotiated directly by phase-plane translational control

The main-engine burn executed as part of TPI is a standard trim burn module which is described in Section 3 of this volume

7 2 1 3 Terminal Phase Transfer

Tracking resumes as soon as possible following TPI to identify, as Tug nears the Target, trajectory errors resulting from initial tracking uncertainties and TPI burn dispersions Any significant errors will be corrected at range-defined gates early in the transfer (Figure 7 2 1-2)

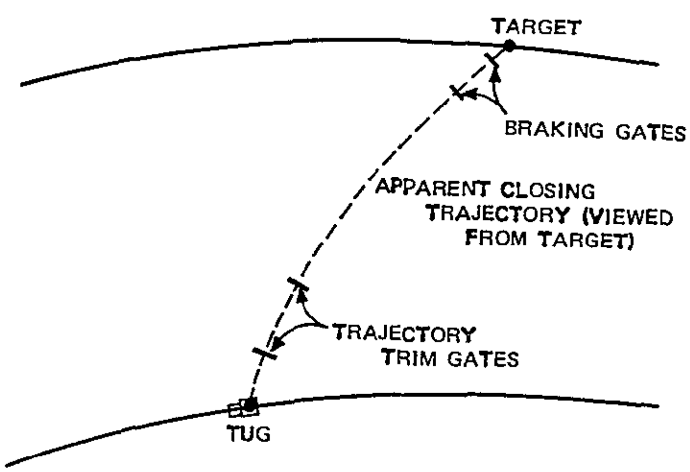


Figure 7 2 1-2 Terminal Phase Transfer

Incorrect Target-relative sidespeed will be manifested as line-of-sight (LOS) angular motion Because of the low LOS angular rates early in the transfer, finite periods of time preceding each gate will be required for measuring the rate relative to the Tug inertial reference

Tug braking as the Transfer is completed will be implemented with at least two small burns rather than one as with TPI This will minimize the likelihood of Target perturbation or contamination by Tug APS exhaust The impulse required at the initial braking gate will be determined or updated following each trajectory trim. The range of this gate will not vary. The second braking gate range and impulse will be functions of the closing velocity One scheme would allow the first braking burn to compensate for 60-90 percent of the TPF impulse requirement, the second gate to brake an equivalent amount, and allow the range, range-rate phase plane initialized following the second braking to distribute the remaining 10-40 percent of the impulse. The range of the second gate would be calculated as a function of closing velocity so that entry into phase-plant control would occur in the dead-band, i.e., no firings will be required immediately at the transition.

The impulse for the final braking would be distributed according to the translational control law so that higher closing velocities cause braking to commence further out from the target rather than increasing the thrusting at a given range

This scheme and classical ones should be analyzed for economic feasibility with a Tug simulation with six degrees of freedom and a propellant slosh model.

The aim of the nominal flow is to transition to the docking module and phase-plane translational control without reverting to stationkeeping Stationkeeping may occur as part of the Docking Inspection and Alignment submodule, to be discussed later, but this will be at a minimum non-docking approach range

7 2 2 Docking Operations

This module includes Inspection and Alignment, Closure, and Terminal Docking. It is principally distinguished from Rendezvous operations by the Tug maneuvering in response to the relative attitude of the Target A presumption for this flow description is that the Target attitude will be stable but will not change to aid Tug alignment Additionally, some identifiable and standard docking targets such as corner-cube reflectors will be installed on the target for aiding the docking tracker

7 2 2 1 Docking Inspection and Alignment

This submodule consists of closing to the minimum safe-approach range, the radius of the safety sphere, and maneuvering about the target to support inspection via the television camera and the docking-aid search by the tracker (Figure 7 2 2-1)

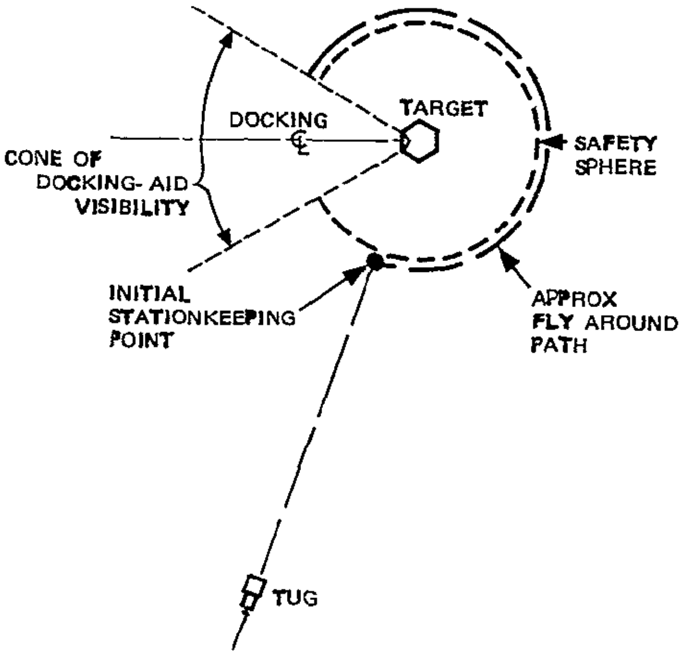


Figure 7 2.2-1 Docking Inspection and Alignment

The radius of the safety sphere will be a function of the target Spacecraft The sphere will be sufficiently large to be standard for all Spacecraft to be inspected by Tug This would be consonant with operational standardization Additional constraints on the inspection orbit radius are the TV camera field-of-view, the docking tracker field-of-view and the docking-aid visibility cone The distance from the Tug to the target will be sufficient for both the TV and docking tracker fields-of-view to contain the entire Spacecraft, thus requiring no maneuvering of the Tug attitude other than that required to maintain the Tug pointed directly toward the center of the Spacecraft

Inspection will be flown as a combination of a maximum of four orbits about the target Once inspection is completed, as determined by the SOC and signaled via a discrete command from the TOC, the Tug will proceed directly to the docking visibility cone, if it has been previously intersected Otherwise the isometric search will continue for the maximum of four circumnavigations about the target Failure to acquire will be an anolmaly If the docking-aid visibility cone subtends a solid angle greater than ninety degrees, two circumnavigation orbits would be sufficient for acquisition and alignment The completion of alignment will occur when the docking aids are in sight and being tracked Closure can then commence immediately, assuming, of course, that inspection has been signaled complete

7 2 2 2 Docking Closure

A closing-velocity component is established while lateral displacement error is being nulled (Figure 7 2.2-2)

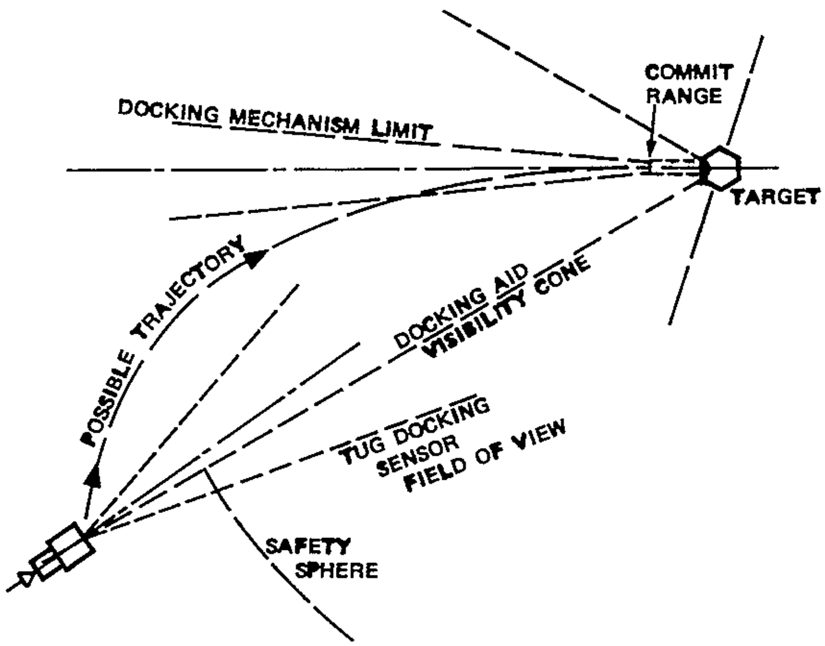


Figure 7.2 2-2 Docking Closure

Lateral displacement and attitude angle error by Tug is not significant as long as the docking tracker is locked on, but when the Tug is sufficiently near the Target for the imminent onset of docking tracker attitude blindness. the lateral and angular errors must be within the allowable docking latch tolerance The range of this blindness gate is called the Commit Range

Various closure control law possibilities can be postulated. One obvious one would establish a closing velocity when the docking-aid track is established and null the lateral error during the closure A simpler law would null the Tug lateral displacement error and then close directly down the docking axis The assessment of the various control laws requires a dynamic simulator with a slosh model and allowing interaction to simulate ground controller functions and to aid real-time analysis

C3

7 2 2 3 Terminal Docking

The satisfaction of Commit Range tolerances allows penetration of the gate with an inertially fixed attitude parallel to the docking axis, with lateral errors always within the latch-permissible ranges and with the optimum contact velocity (Figure 7.2 2 3)

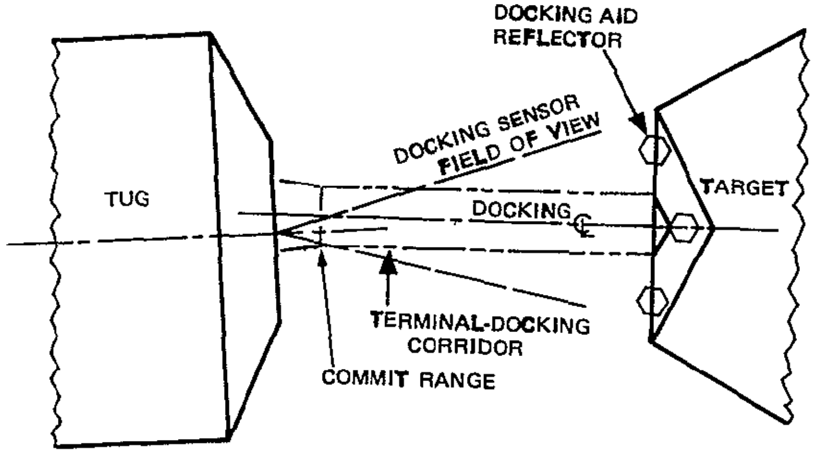


Figure 7 2.2-3 Terminal Docking

Range can be continuously monitored by the docking tracker, technology permitting, through the use of a single target or reflector as long as one is in view Significant interactions exist in Terminal Docking attitude blink ranges, totally blind ranges, RCS lateral deadband, slosh, and contact dynamics These parameters and their relations will be defined and analyzed with a Tug dynamic simulator including a detailed slosh model

7 2 3 Non-Nominal Paths

A failure to acquire the Target during Rendezvous Acquisition will prevent the execution of an optimal TPI Burn The TOC would have the option of commanding the Tug to bypass Acquisition and execute TPI with the presumption that the tracker will acquire during the Transfer High-quality Tug navigation and a low-range tracker could yield such a situation The basic flow would proceed as defined but Tug autonomy and efficiency may be changed

An inadvisable transfer, as referred to in Section 7 2 1 2, is one requiring a prohibitive impulse expenditure This could occur if the Tug were below and ahead of the Spacecraft or above and behind the Spacecraft The immediate reaction to such a transfer will be the definition via real-time mission planning of one or more transfer or phasing orbits to place the Tug in a favorable position for Rendezvous initiation. Being forced into unpredicted phasings and transfers will require a complete redefinition and prioritization of the balance of the Tug mission

Failure of the television system onboard would not of itself prevent any of the critical functions from executing but a valuable supervisory tool would be removed Extensive ground processing of rendezvous tracker, docking tracker, inertial system attitude, Tug navigation state and Target inertial attitude may result in artificial intelligence approximating a TV picture but the advisability of defining the system required to support such a capability is not clear

Failure of the docking sensor to acquire when the television indciates visibility of the docking-aid targets is an anomaly because the baseline system for this study depends upon a scanning laser radar for relative attitude, and range information However, television may be a suitable docking sensor, given adequate support displays, and software and controls.

Failure to latch at Terminal Docking contact will cause the Tug to automatically revert to Commit Range for attitude and state reassessment. An uplinked release command by TOC is required before Terminal Docking is attempted again

7 2 4 Operational Parameter Definitions and Relations

Once the submodules were functionally segregated, the variables active in each function were identified. Because this was an initial effort, compiling an initial set of representative and significant parameters was emphasized rather than gleaning for an exhaustive set (Table 7 2 4-1)

The worth of the compilation lay in defining the interaction of the parameters. Of particular interest were the module interfaces at the entry to Rendezvous Acquisition and at the exit from Terminal Phase Transfer. Three types of relationships are shown Figures 7 2 4-1 through 7 2 4-24 illustrate the relation between acquisition range and the time remaining until TPI for various differential height and targetted transfer angles These curves can be employed for evaluating the impact of a minimum time requirement between acquisition and the TPI boost

The relations between example TPI impulse budgets and targetted optimal transfer arcs for several differential heights at each of the target altitudes are illustrated in Figures 7 2 4-25 through 7 2 4-27 The impulse budget constraint causes favoring of minimal differential heights or long transfer arcs The example budgets are included as aids for chart interpretation

Each optimal Lambert transfer may be characterized at TPI by the slant range between the two vehicles These slant ranges are the minimum acquisition ranges (Figures 7 2 4-28 through 7 2 4-30). These data, already shown in the acquisition range/time-to-TPI relations (Figures 7 2.4-1 through 7 2 4-24) are illustrated here with emphasis on the relation between impulse-possible transfer arcs and required minimum acquisition range When the two charts for a given target altitude (e g., 7.2.4-25 and 7 2 4-28) are viewed together, the effect of the impulse budget on the minimum required acquisition range is visible (Table 7 2 4-2) For the illustrated differential heights, transfer angles and target attitudes, the minimum requirements varies from 15 to 73 nmi at 900 nmi , 25 to 132 nmi at 7,000 nmi and 10 5 to 78 nmi at 19,365 nmi If the current baseline Scanning Laser Radar (SLR), which has an acquisition range of approximately 45 nmi , were employed as the rendezvous tracker, the set of possible transfers would be significantly constrained as a review of Figures 7 2.4-18 through 7 2.4-30 indicates.

Table 7 2 4-1 Significant Rendezvous and Docking Parameters

SUBMODULE	PARAMETERS
RENDEZVOUS ACQUISITION	TARGET ALTITUDE TUG ALTITUDE DIFFERENCE (ΔH) CENTRAL ANGLE ($\Delta\Phi$) RENDEZVOUS TRACKER ACQUISITION RANGE RENDEZVOUS TRACKER FIELD OF VIEW TUG NAVIGATION DISPERSIONS
TERMINAL PHASE INITIATION	TPI, TPF IMPULSE BUDGETS MAIN ENGINE MODE MAIN ENGINE MODE INITIALIZATION TIME TUG MANEUVER RATE BURN DURATION
TERMINAL PHASE TRANSFER	BURN DISPERSIONS (IMPULSE, MISALIGNMENT) TRAJECTORY TRIM GATE RANGE CLOSING SPEED LOS ANGULAR RATE BRAKING IMPULSE PRIMARY BRAKING GATE RANGE, IMPULSE SECONDARY BRAKING GATE RANGE, IMPULSE DOCKING TRACKER ACQUISITION RANGE PHASE-PLANE CONTROL LAW
DOCKING INSPECTION & ALIGNMENT	SAFETY SPHERE RADIUS TELEVISION DETAIL DISCRIMINATION TELEVISION FIELD OF VIEW DOCKING TRACKER FIELD OF VIEW DOCKING TRACKER SEARCH CYCLE RATE PHASE-PLANE CONTROL LAW RCS IMPULSE BUDGET
DOCKING CLOSURE	DOCKING-AID CONE OF VISIBILITY TELEVISION FIELD OF VIEW DOCKING TRACKER FIELD-OF-VIEW DOCKING-AID CONFIGURATION LATERIAL CONTROL STABILITY CONTACT FORCE REQUIREMENT CONTACT ANGULAR, DISPLACEMENT TOLERANCES DOCKING TRACKER BLIND RANGE

Table 7 2 4-2 Parametric Relation Example Summary

EXAMPLE SUMMARY

TARGET ALTITUDE (NM)	EXAMPLE TPF ΔV BUDGET (M/S)	DIFFERENTIAL HEIGHT (NM)	TRANSFER ANGLE (DCG)	MINIMUM ACQUISITION RANGE (NM)
900	15	10	58 170	15 24 5
		-20	103 170	33-49
		30	140 170	62 73
7000	10	20	48 170	25-49
		-40	87 150	60 87 *
		60	119 150	110 132
19365	5	-10	20 90	10 5 15
		20	31 90	20 5 31
		30	45 90	35 46
		40	58 90	50 62
		50	70 90	67 78

* EXTRAPOLATED

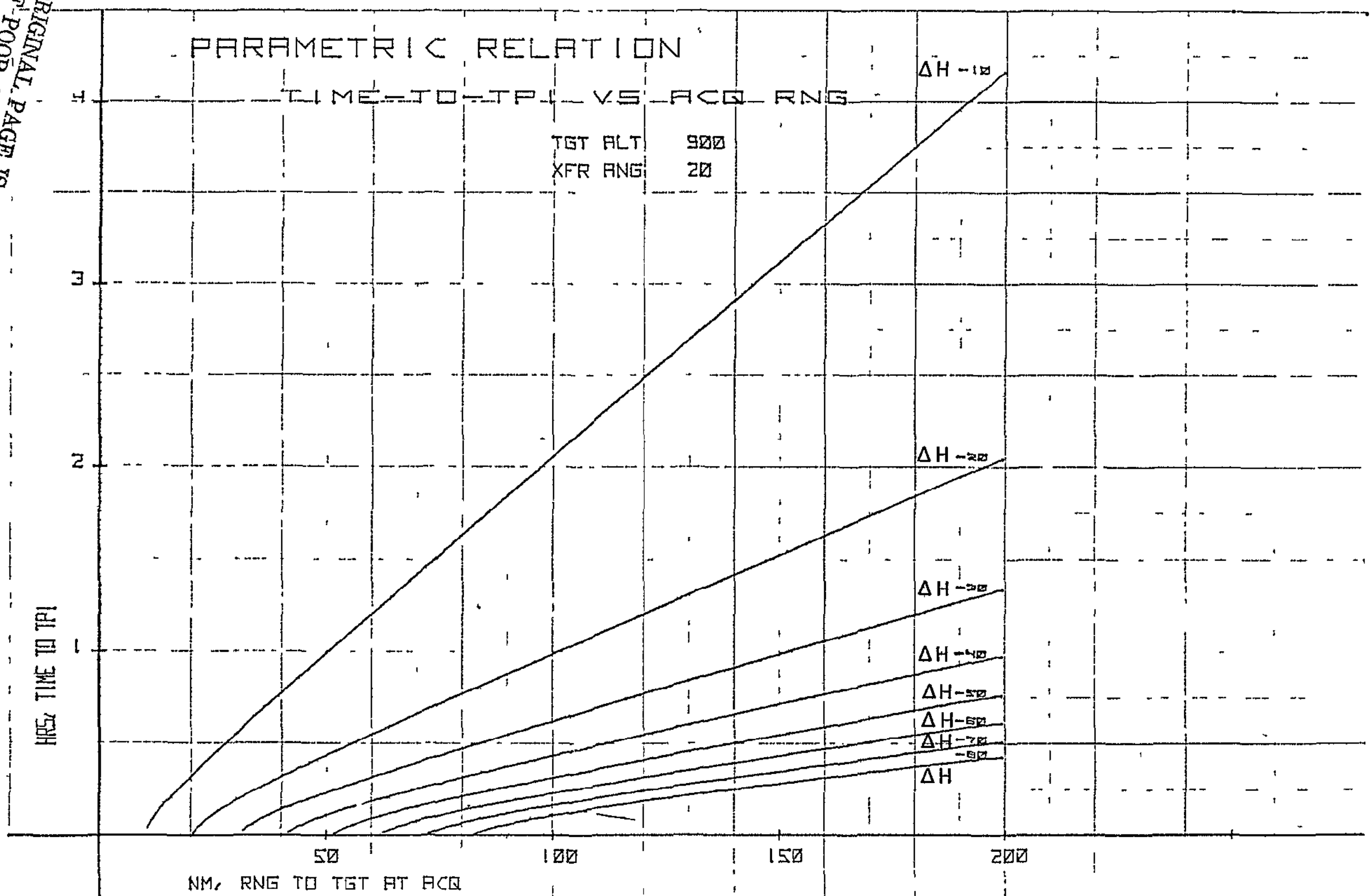


Figure 7.2.4-1 Parametric Relation Between Acquisition Range and Time to TPI for 20 Degree Transfers from Various ΔH at 900 NMI Altitude

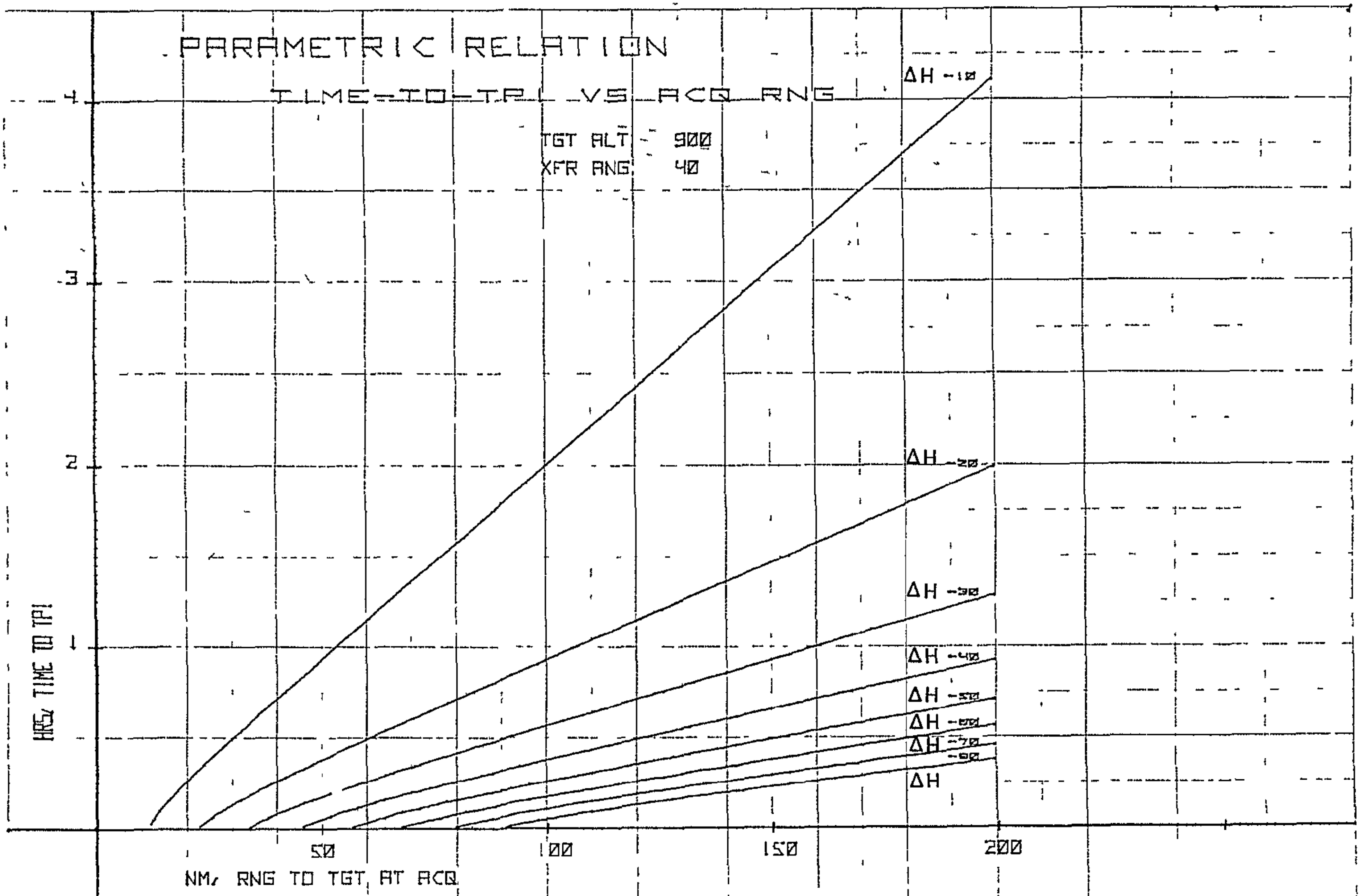


Figure 7.2 4-2 Parametric Relation Between Acquisition Range and Time to TPI for 40 Degree Transfers from Various -ΔH at 900 NMI Altitude

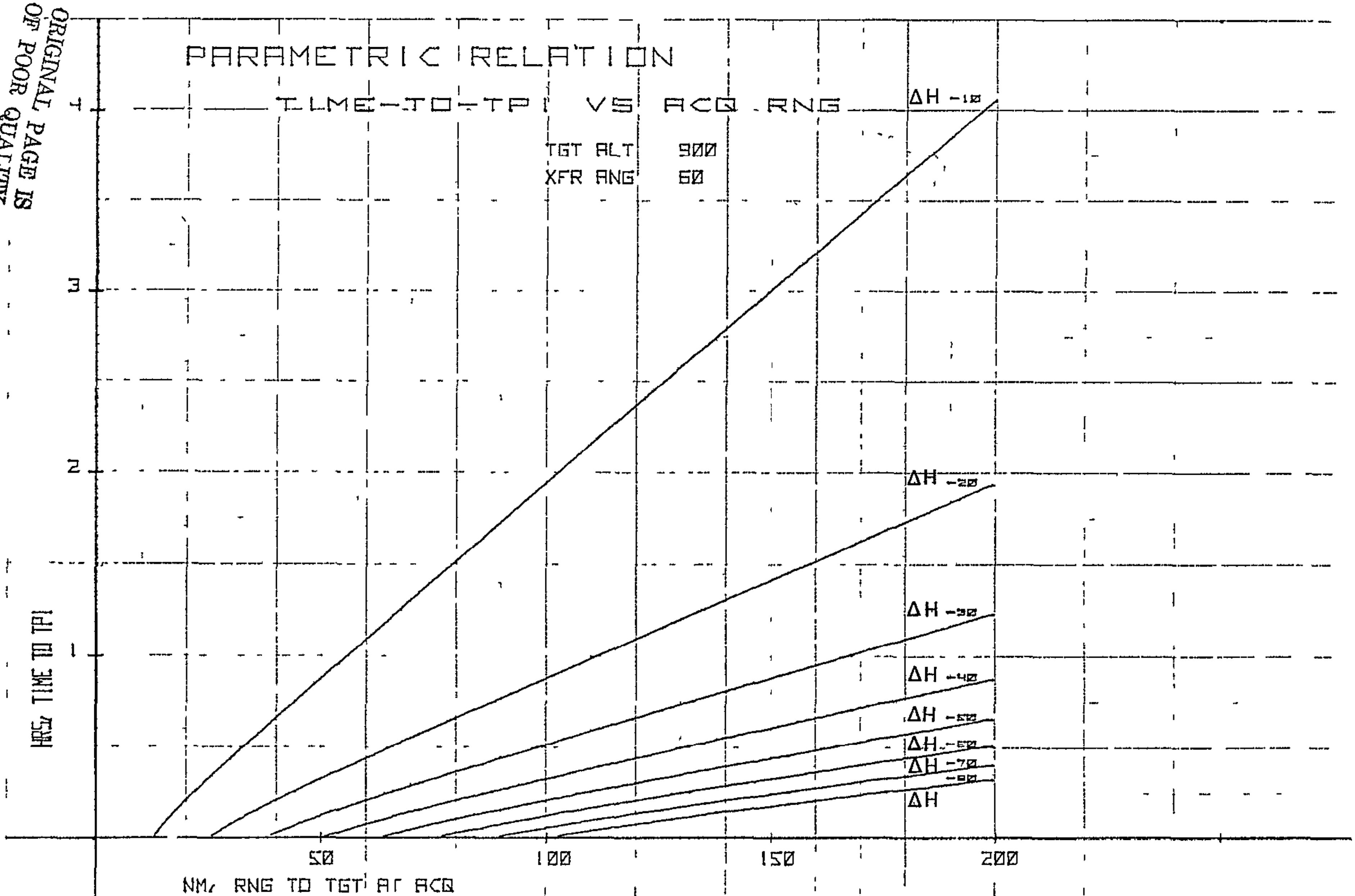


Figure 7 2 4-3 Parametric Relation Between Acquisition Range and Time to TPI for 60 Degree Transfers from Various ΔH at 900 NMI Altitude

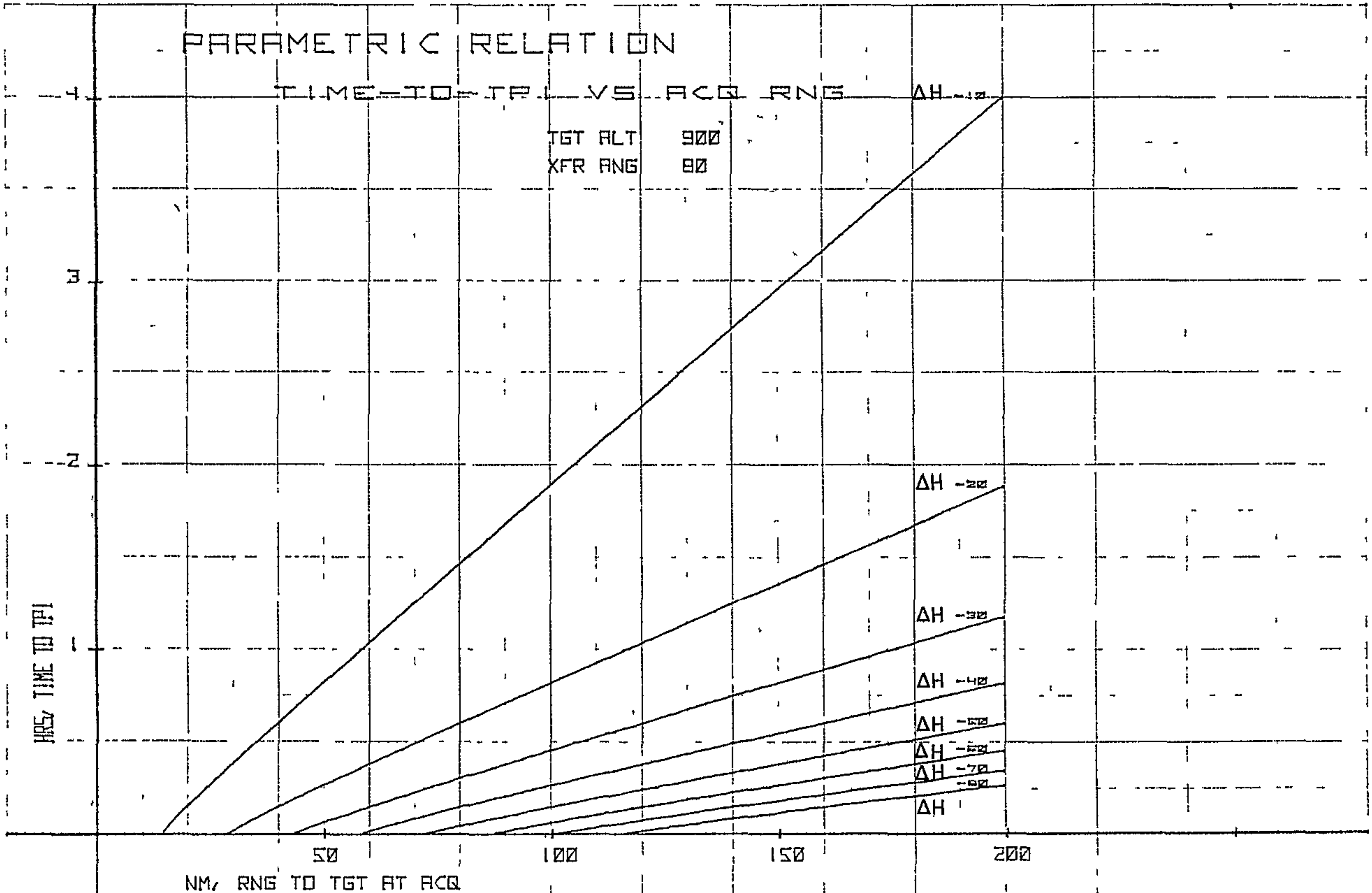


Figure 7.2 4-4 Parametric Relation Between Acquisition Range and Time to TPI for 80 Degree Transfers from Various ΔH at 900 NMI Altitude

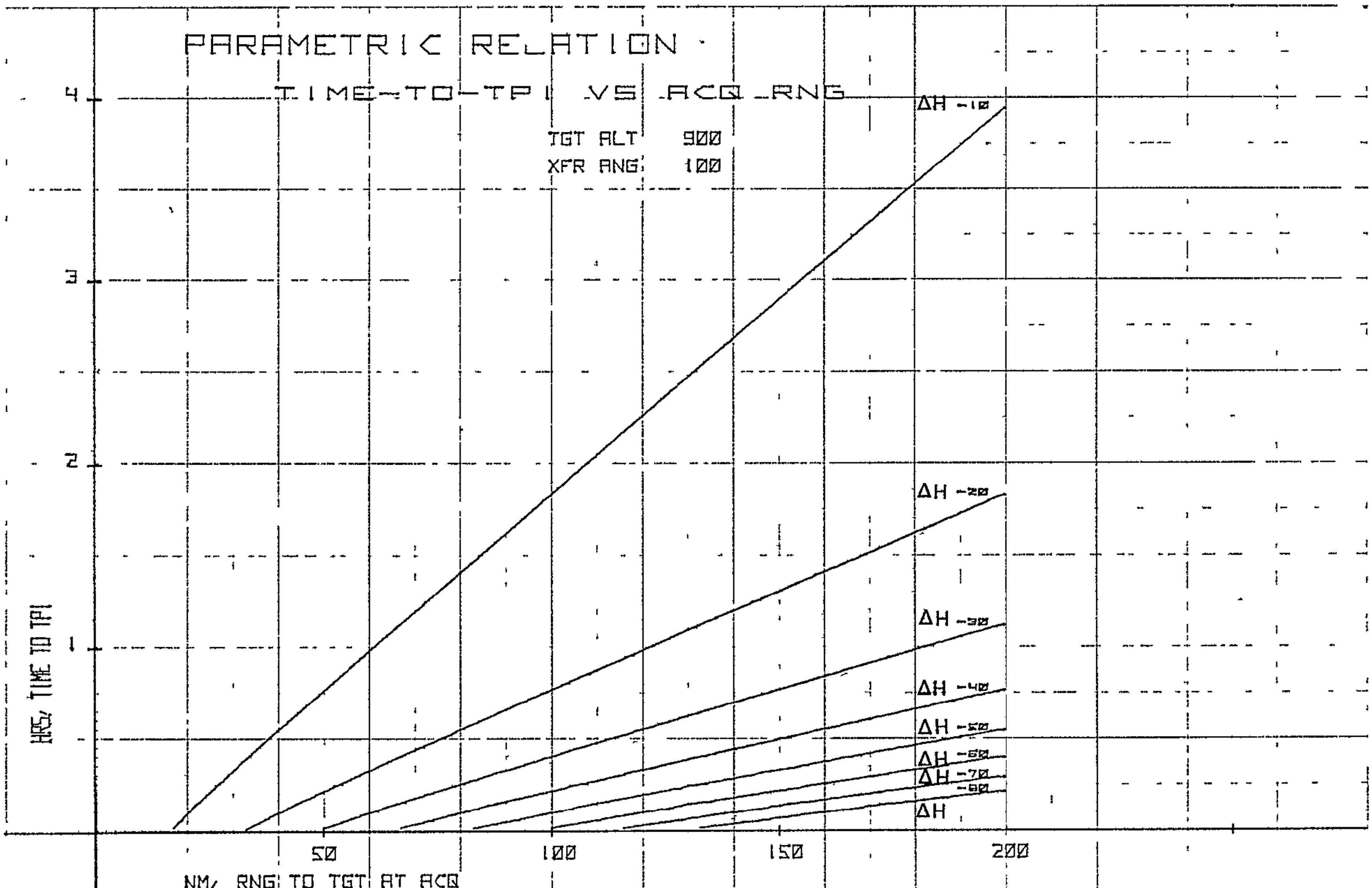


Figure 7 2.4-5 Parametric Relation Between Acquisition Range and Time to TPI for 100 Degree Transfers from Various ΔH at 900 NMI Altitude

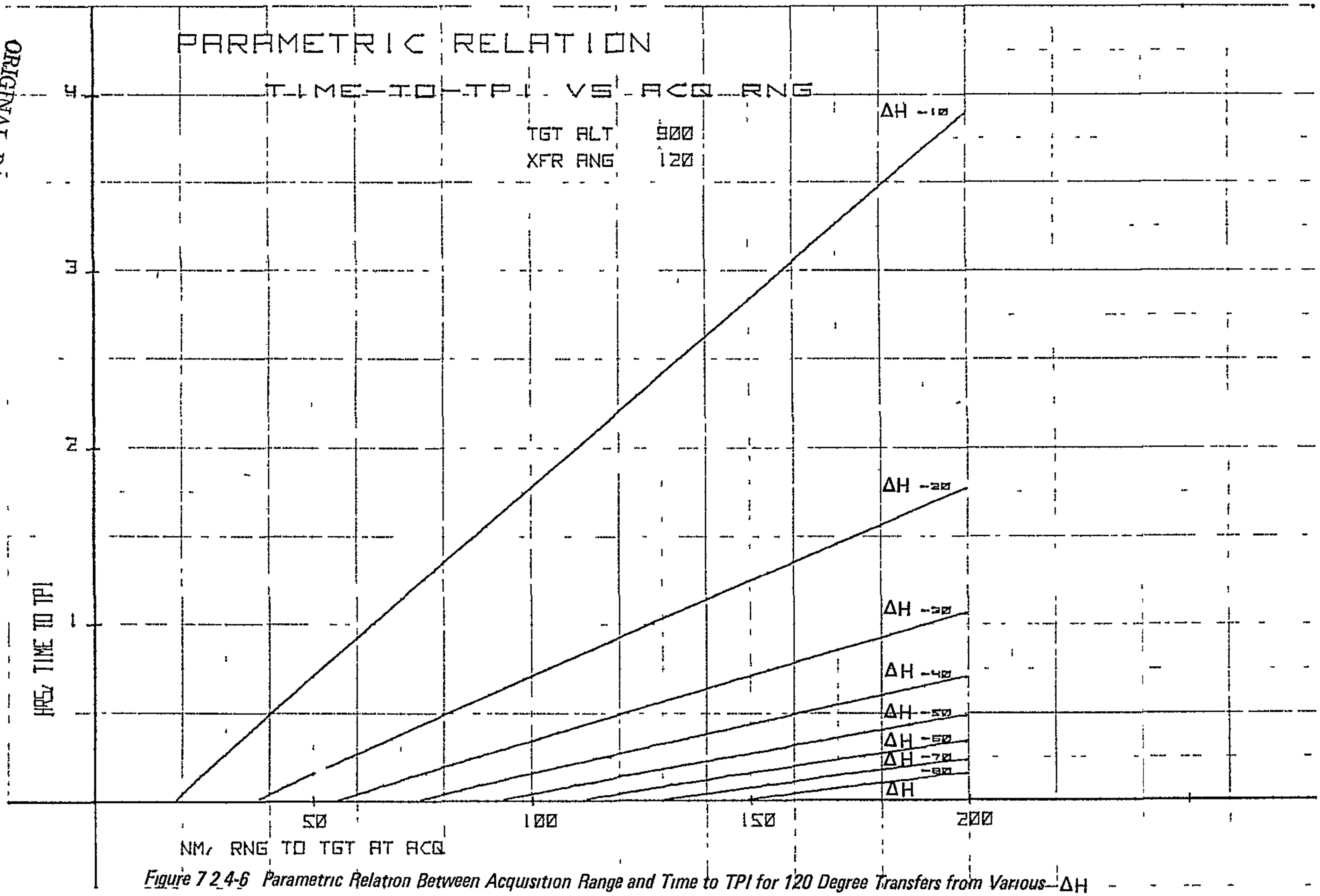


Figure 7 2 4-6 Parametric Relation Between Acquisition Range and Time to TPI for 120 Degree Transfers from Various ΔH at 900 NMI Altitude

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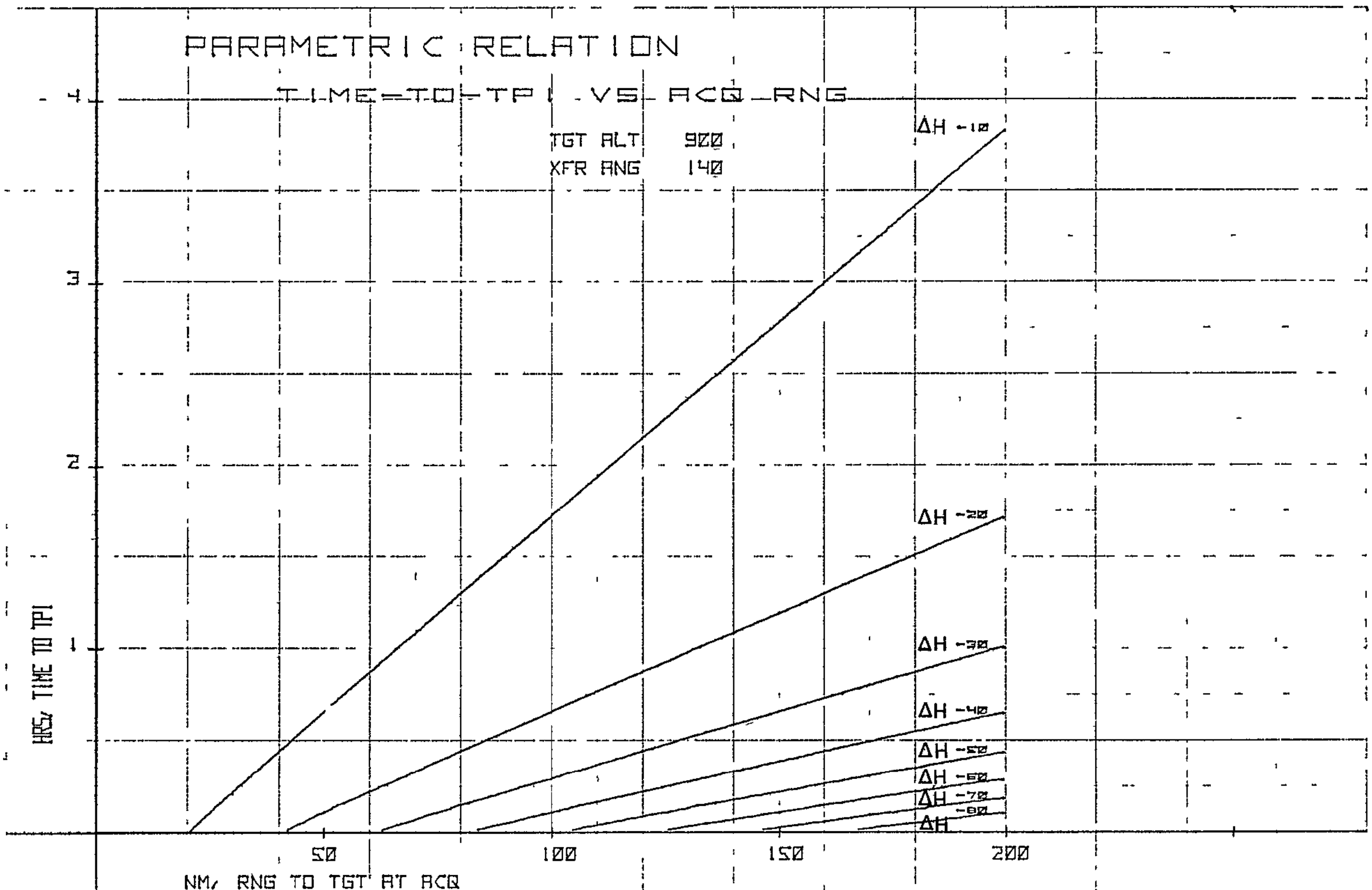

Figure 7.2.4-7 Parametric Relation Between Acquisition Range and Time to TPI for 140 Degree Transfers from Various ΔH at 900 NMI Altitude

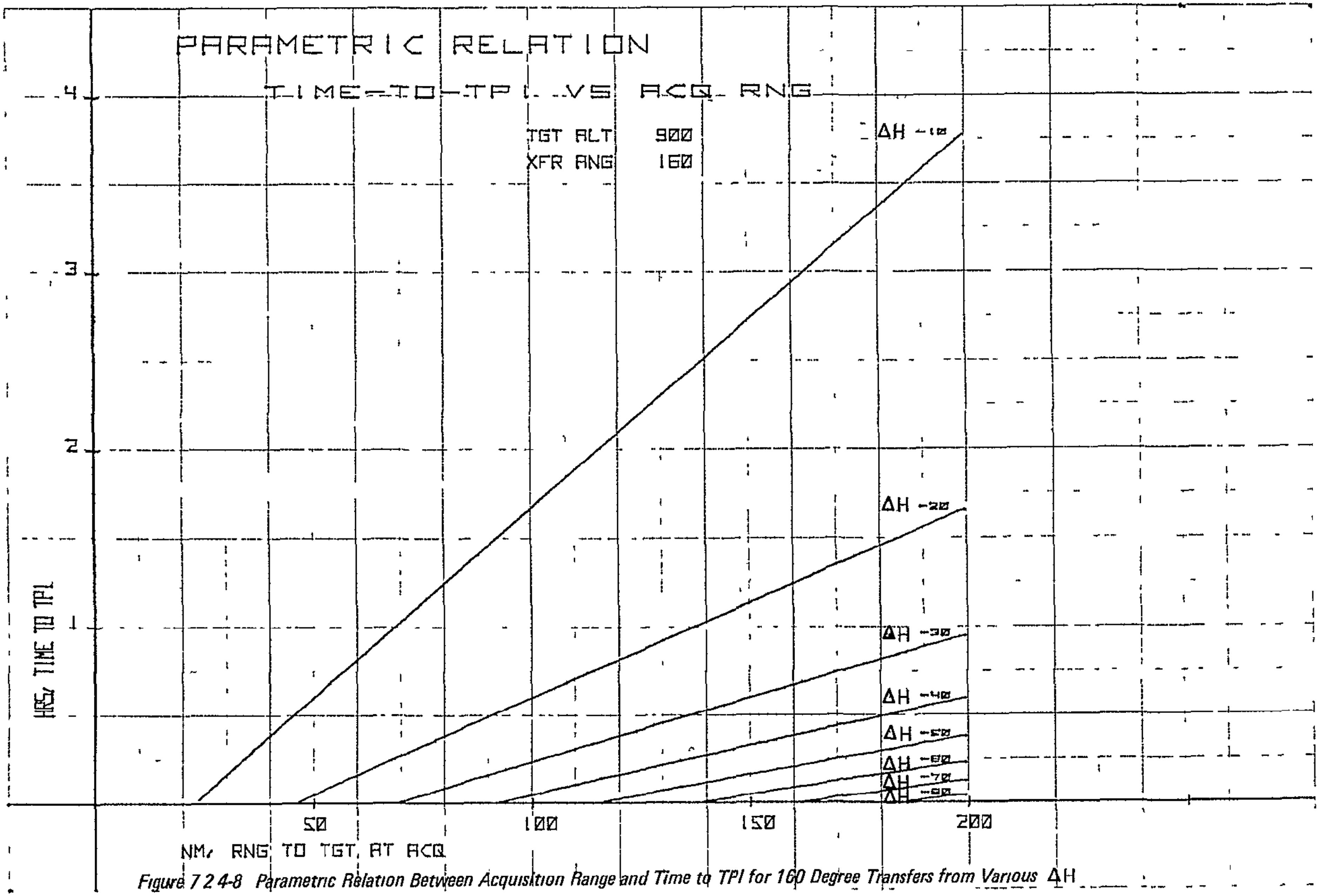

Figure 7 2 4-8 Parametric Relation Between Acquisition Range and Time to TPI for 160 Degree Transfers from Various ΔH at 900 NMI Altitude

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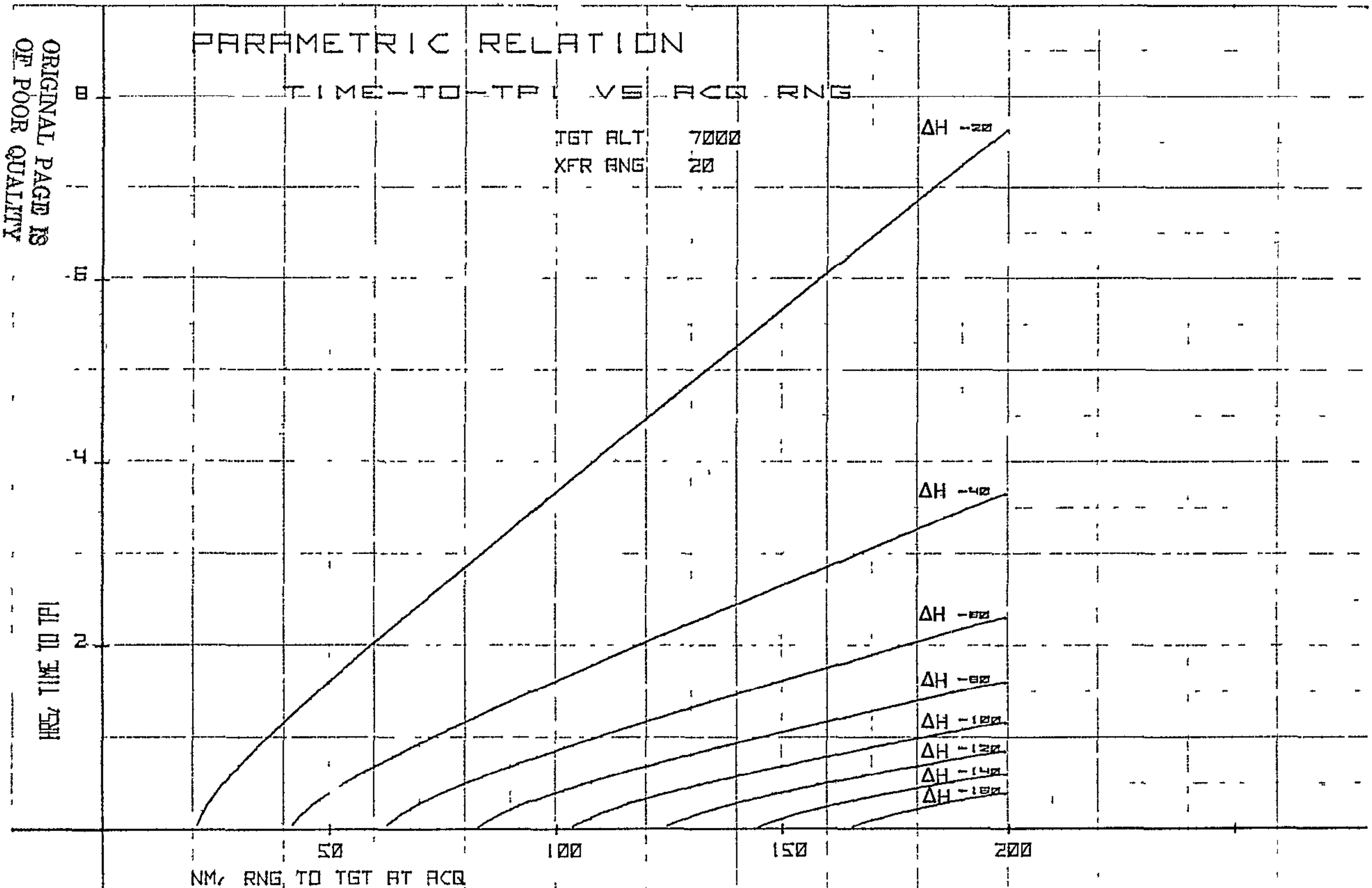

Figure 7 2 4-9 Parametric Relation Between Acquisition Range and Time to TPI for 20 Degree Transfers from Various ΔH at 7000 NMI Altitude

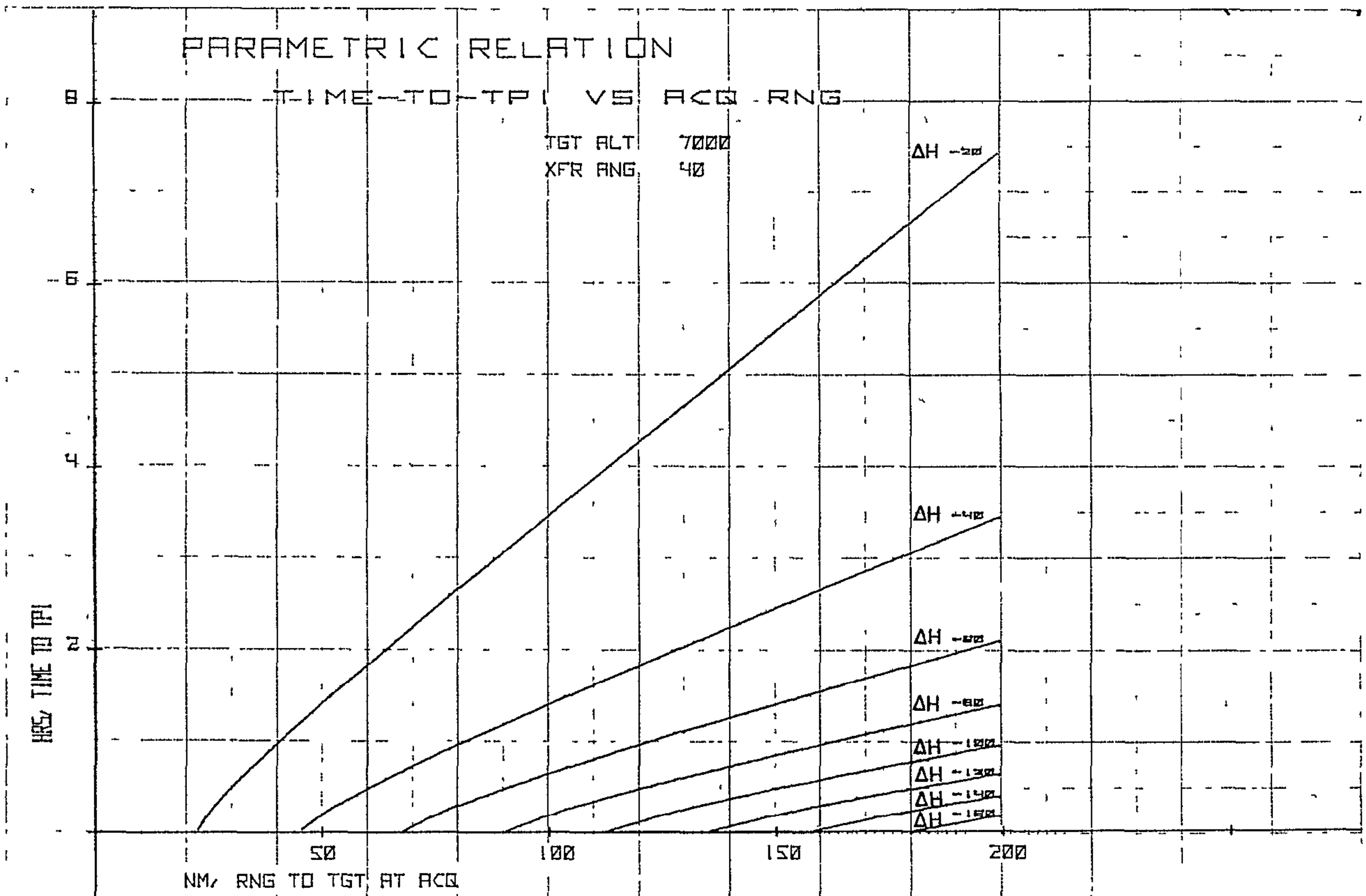

Figure 7 2 4-10 Parametric Relation Between Acquisition Range and Time to TPI for 40 Degree Transfers from Various ΔH at 7000 NMI Altitude

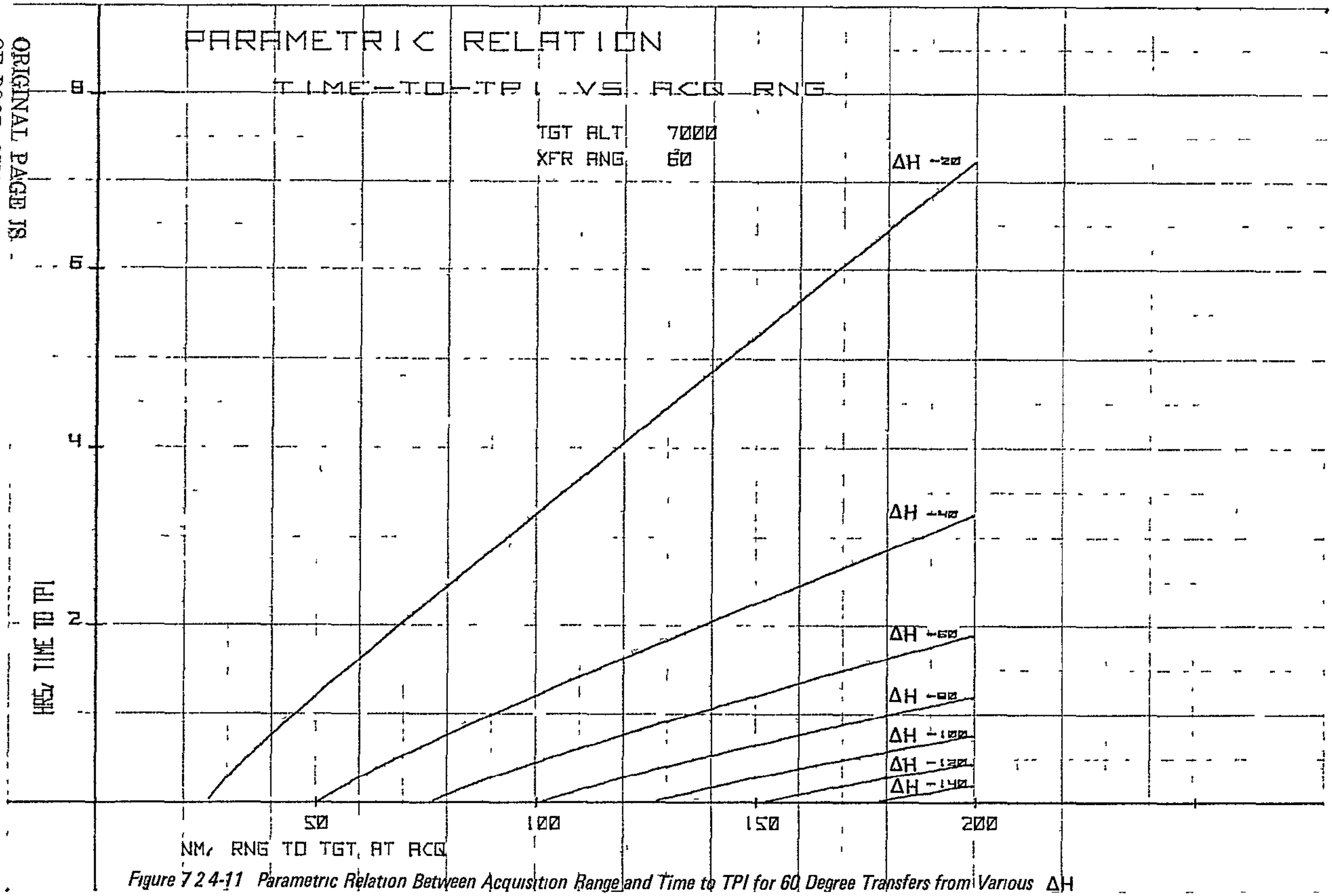

Figure 7 2 4-11 Parametric Relation Between Acquisition Range and Time to TPI for 60 Degree Transfers from Various ΔH at 7000 NMI Altitude

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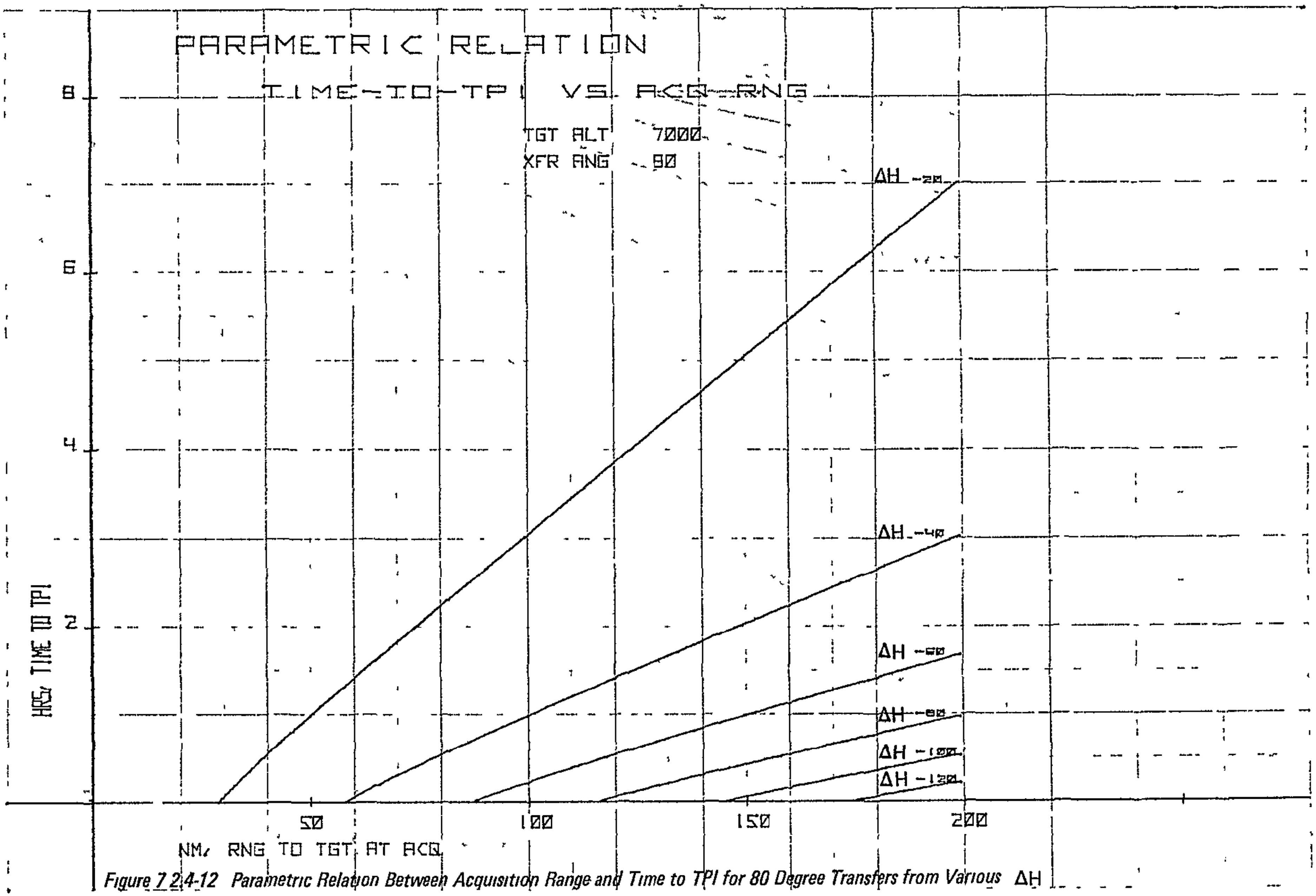

Figure 7 2 4-12 Parametric Relation Between Acquisition Range and Time to TPI for 80 Degree Transfers from Various ΔH at 7000 NMI Altitude

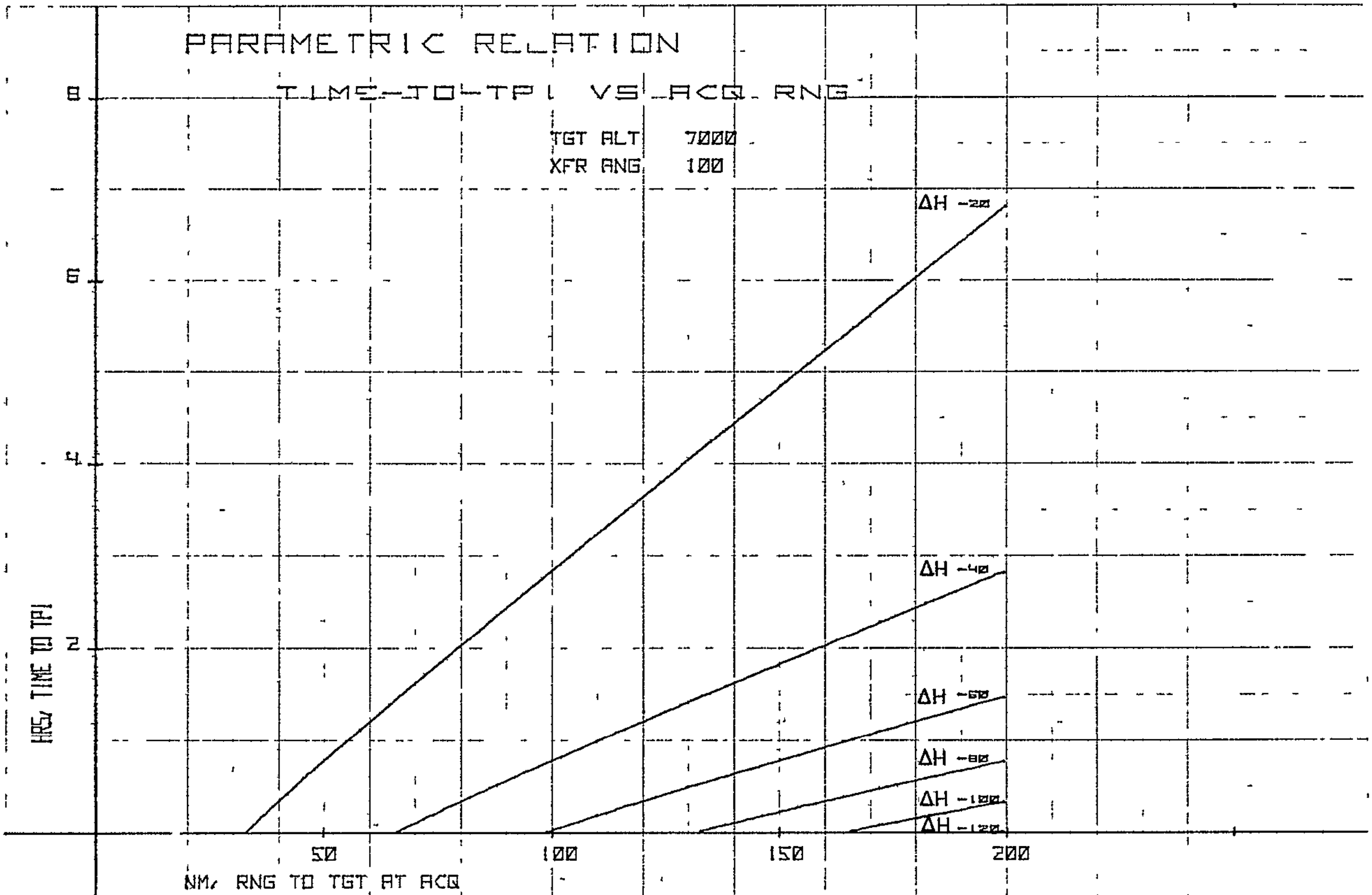

Figure 7 2 4-13 Parametric Relation Between Acquisition Range and Time to TPI for 100 Degree Transfers from Various ΔH at 7000 NMI Altitude

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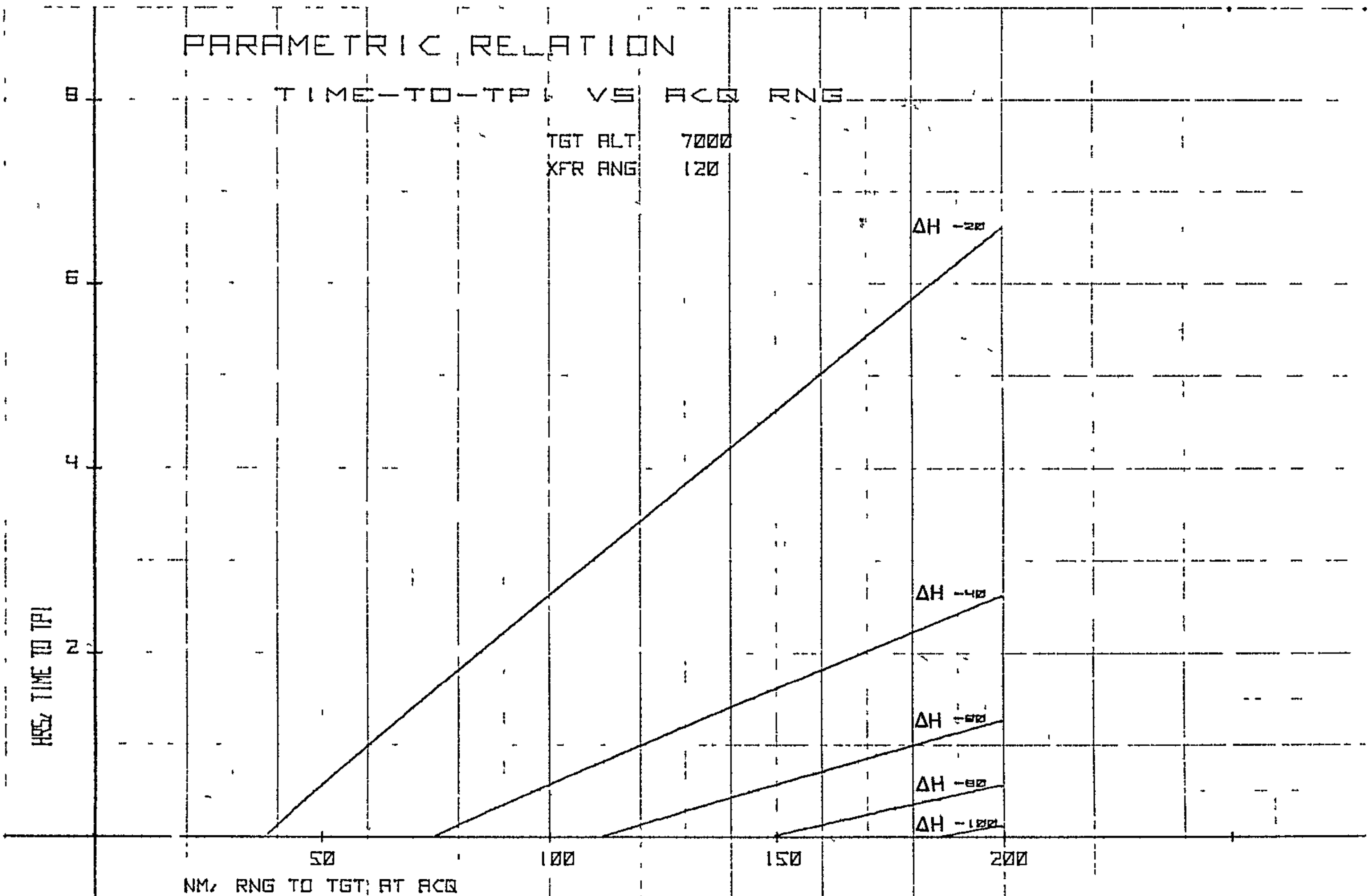

Figure 7 2 4-14 Parametric Relations Between Acquisition Range and Time to TPI for 120 Degree Transfers from Various ΔH at 7000 NMI Altitude

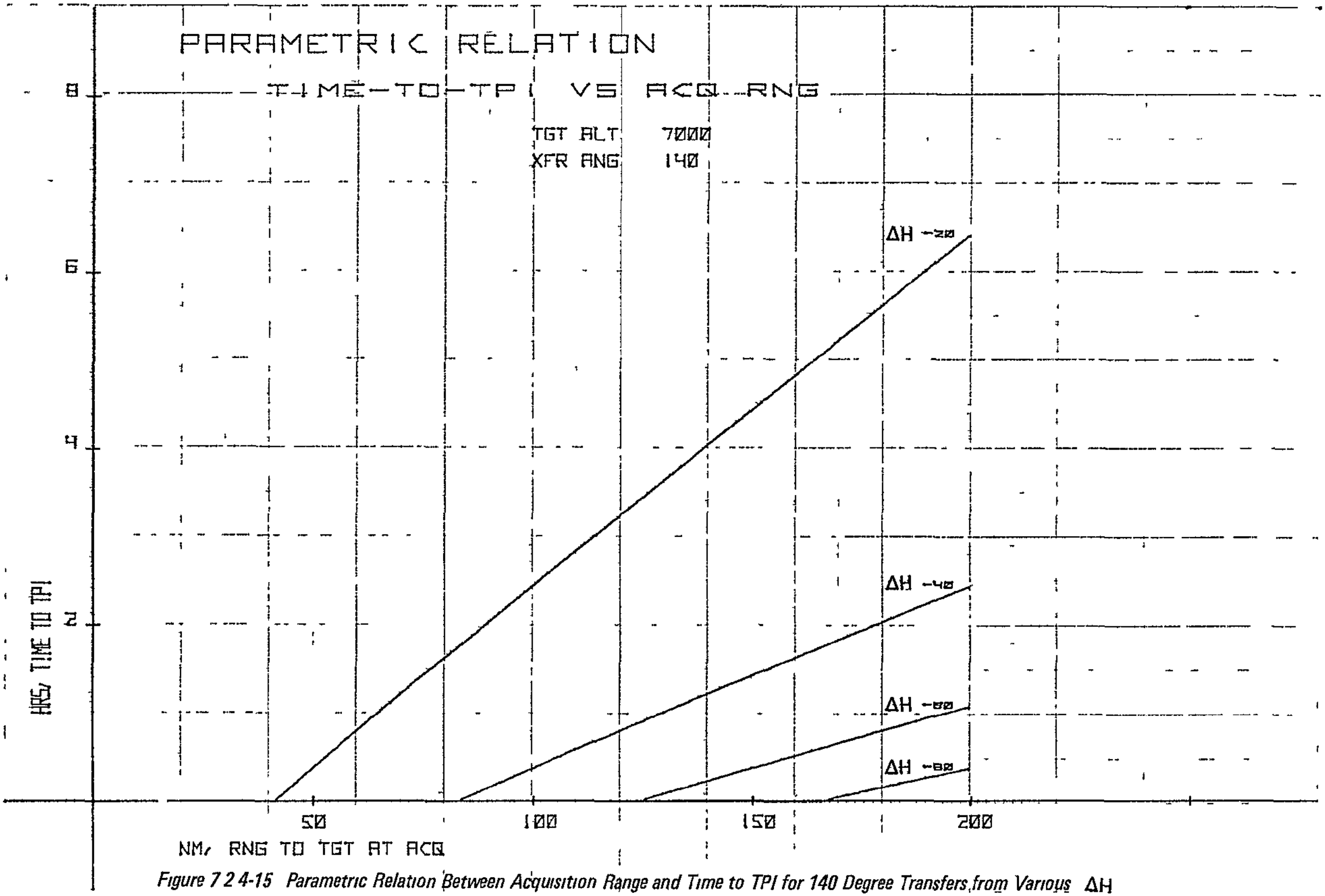

Figure 7 2 4-15 Parametric Relation Between Acquisition Range and Time to TPI for 140 Degree Transfers from Various ΔH at 7000 NMI Altitude

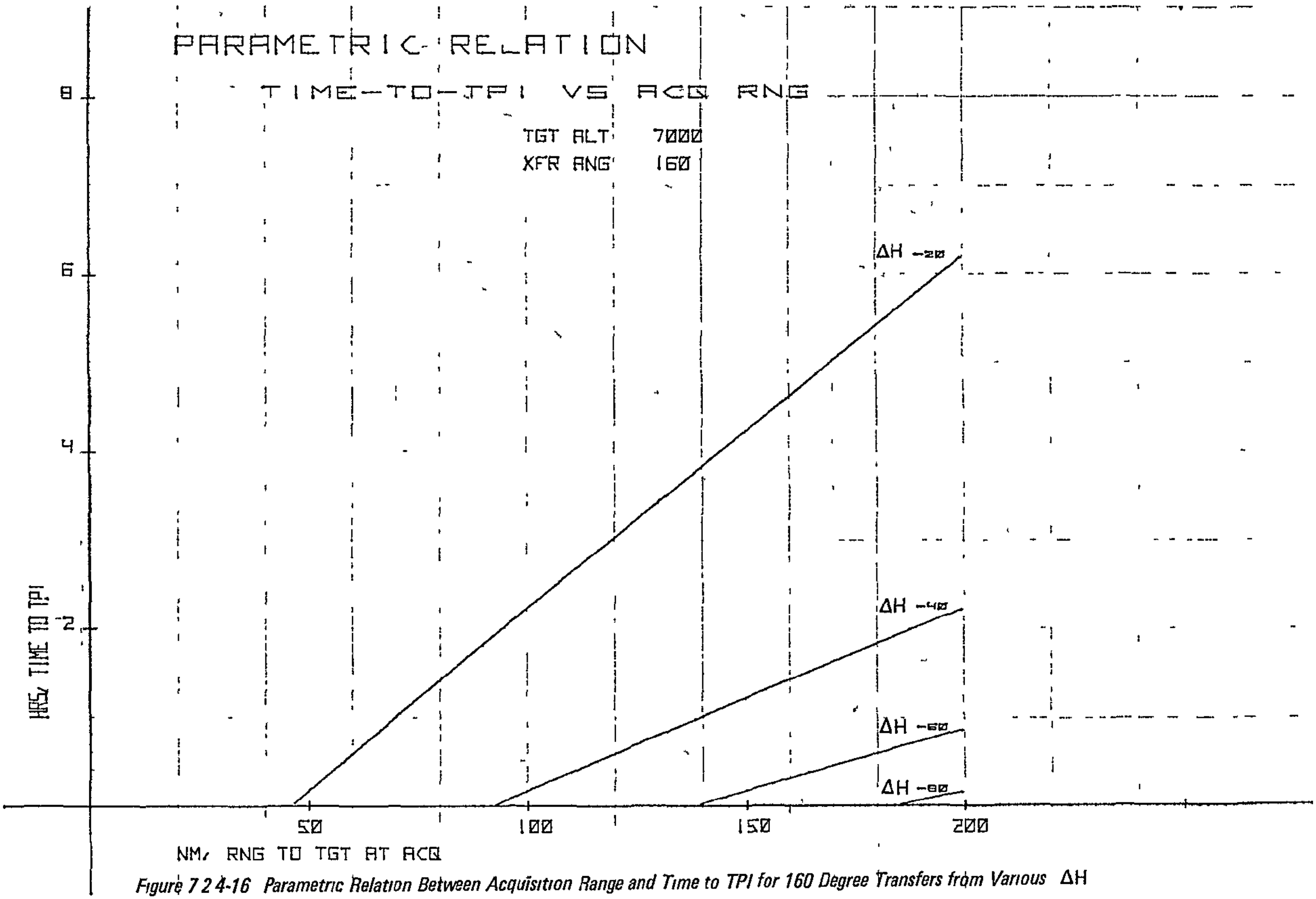

Figure 7 2 4-16 Parametric Relation Between Acquisition Range and Time to TPI for 160 Degree Transfers from Various ΔH at 7000 NMI Altitude

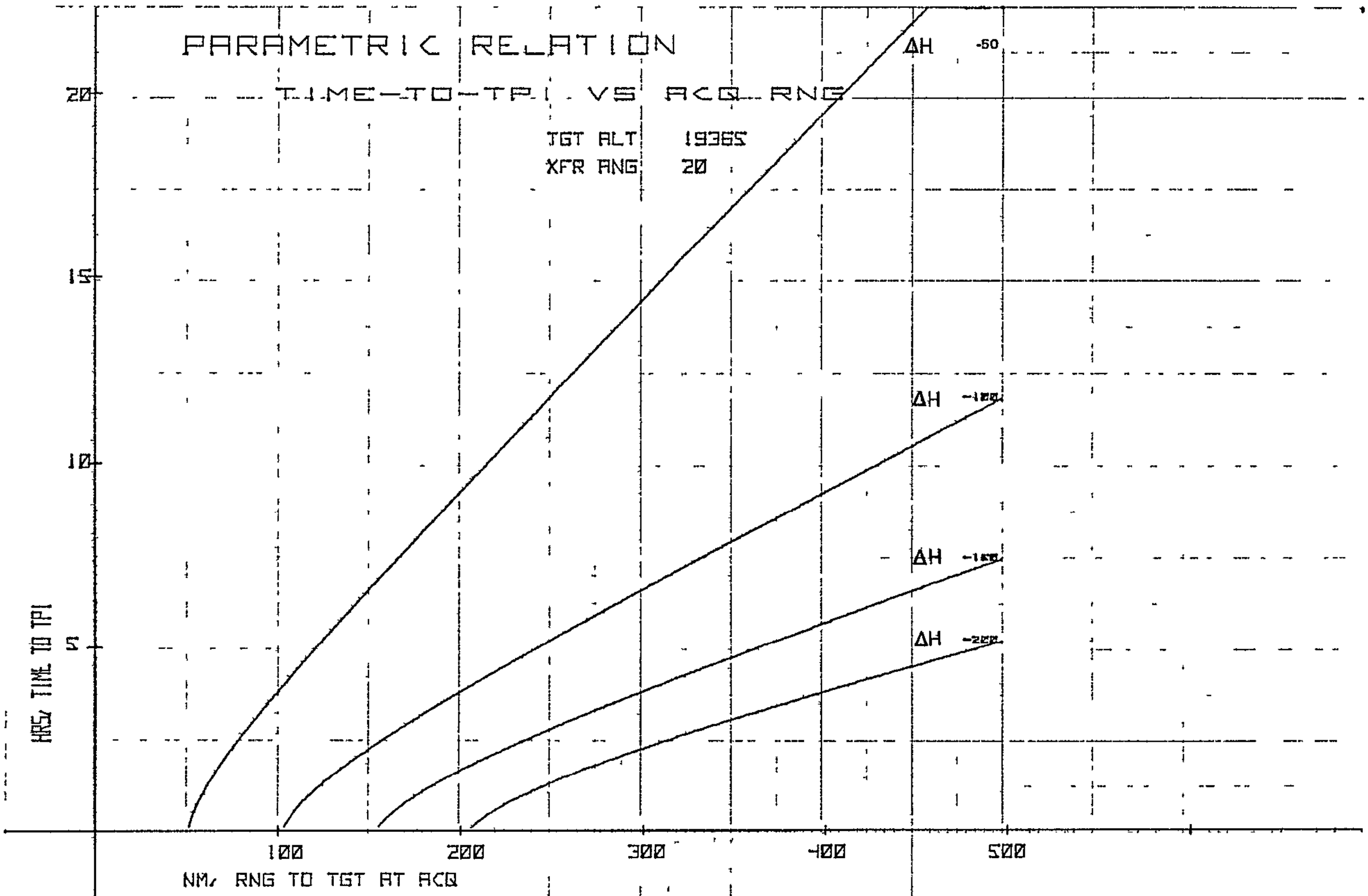

Figure 7 2 4-17 Parametric Relation Between Acquisition Range and Time to TPI for 20 Degree Transfers from Various ΔH at 19365 NMI Altitude

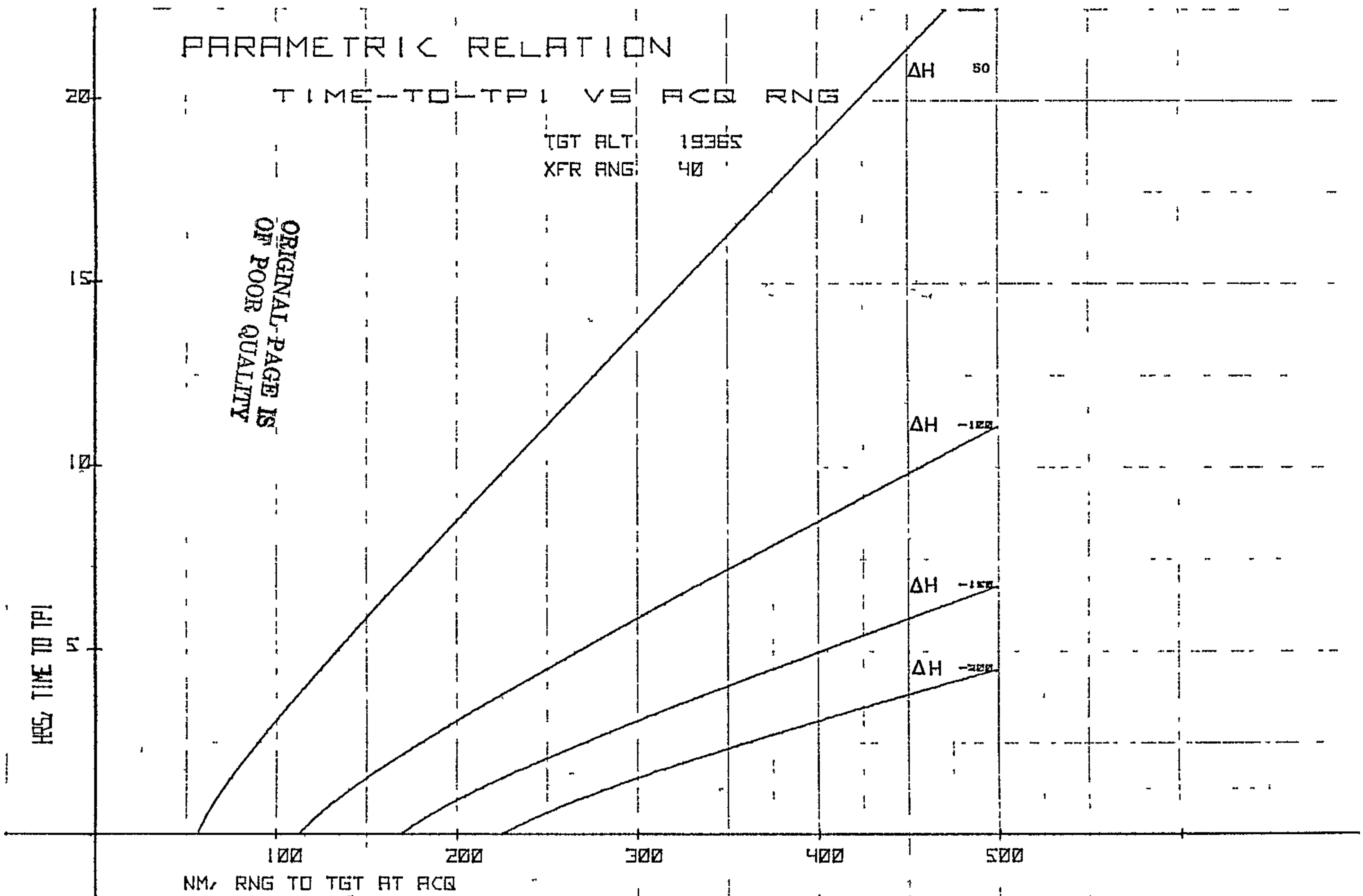

Figure 7.2.4-18 Parametric Relation Between Acquisition Range and Time to TPI for 40 Degree Transfers from Various ΔH at 19365 NMI Altitude

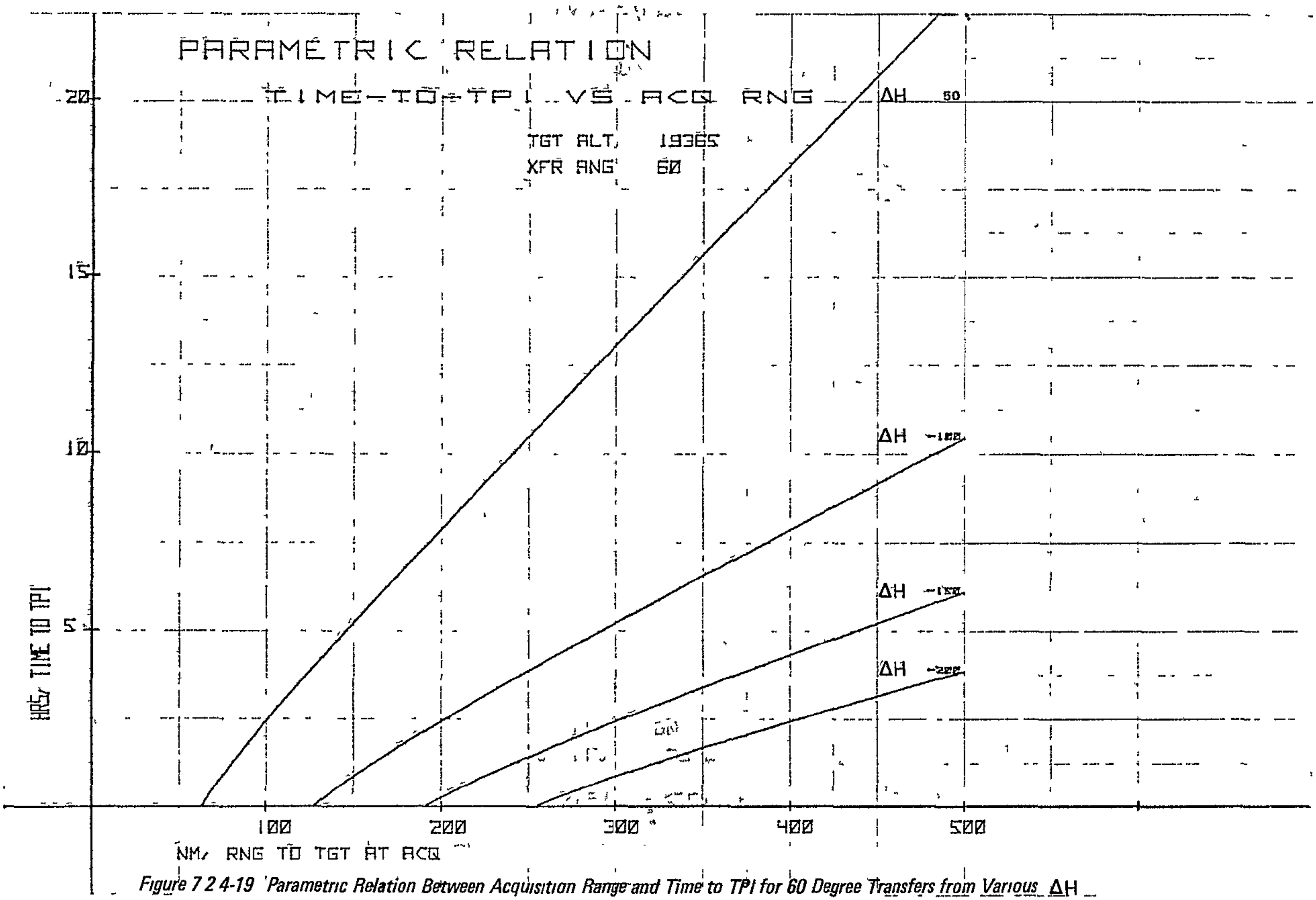

Figure 7 2 4-19 Parametric Relation Between Acquisition Range and Time to TPI for 60 Degree Transfers from Various ΔH at 19365 NMI Altitude

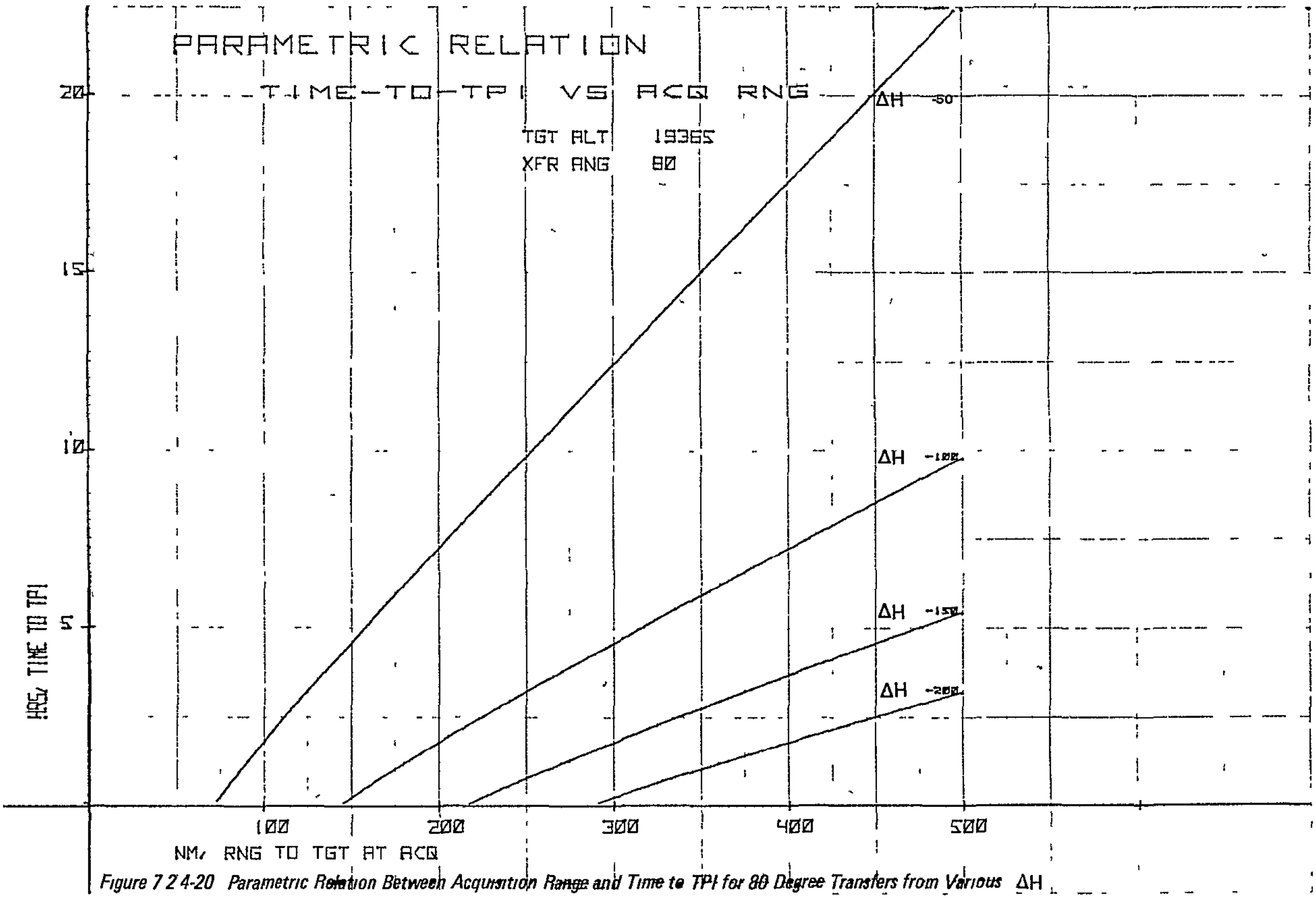

Figure 7 2 4-20 Parametric Relation Between Acquisition Range and Time to TPI for 80 Degree Transfers from Various ΔH at 19365 NMI Altitude

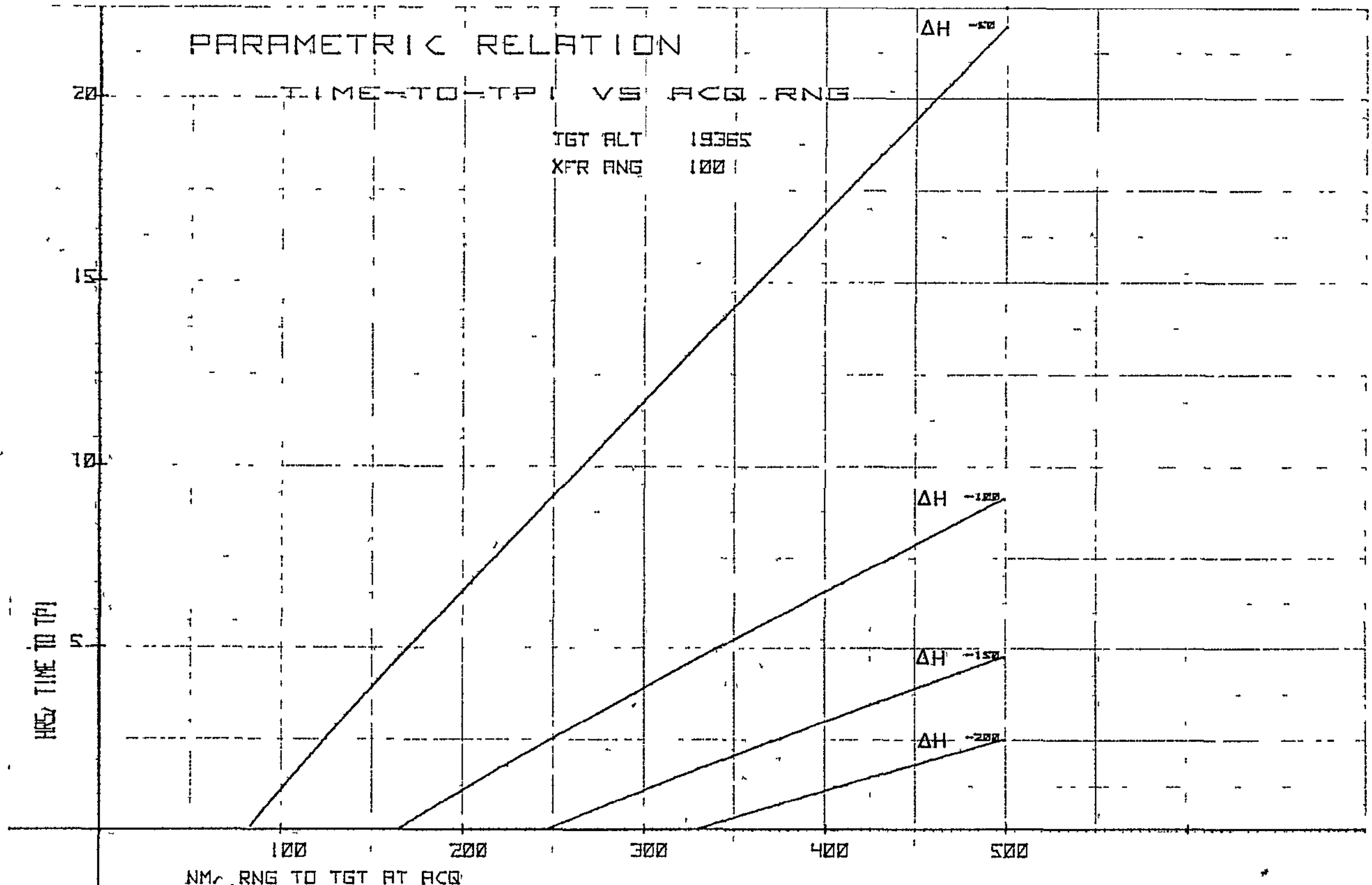

Figure 7 2 4-21 Parametric Relation Between Acquisition Range and Time to TPI for 100 Degree Transfers from Various ΔH at 19365 NMI Altitude

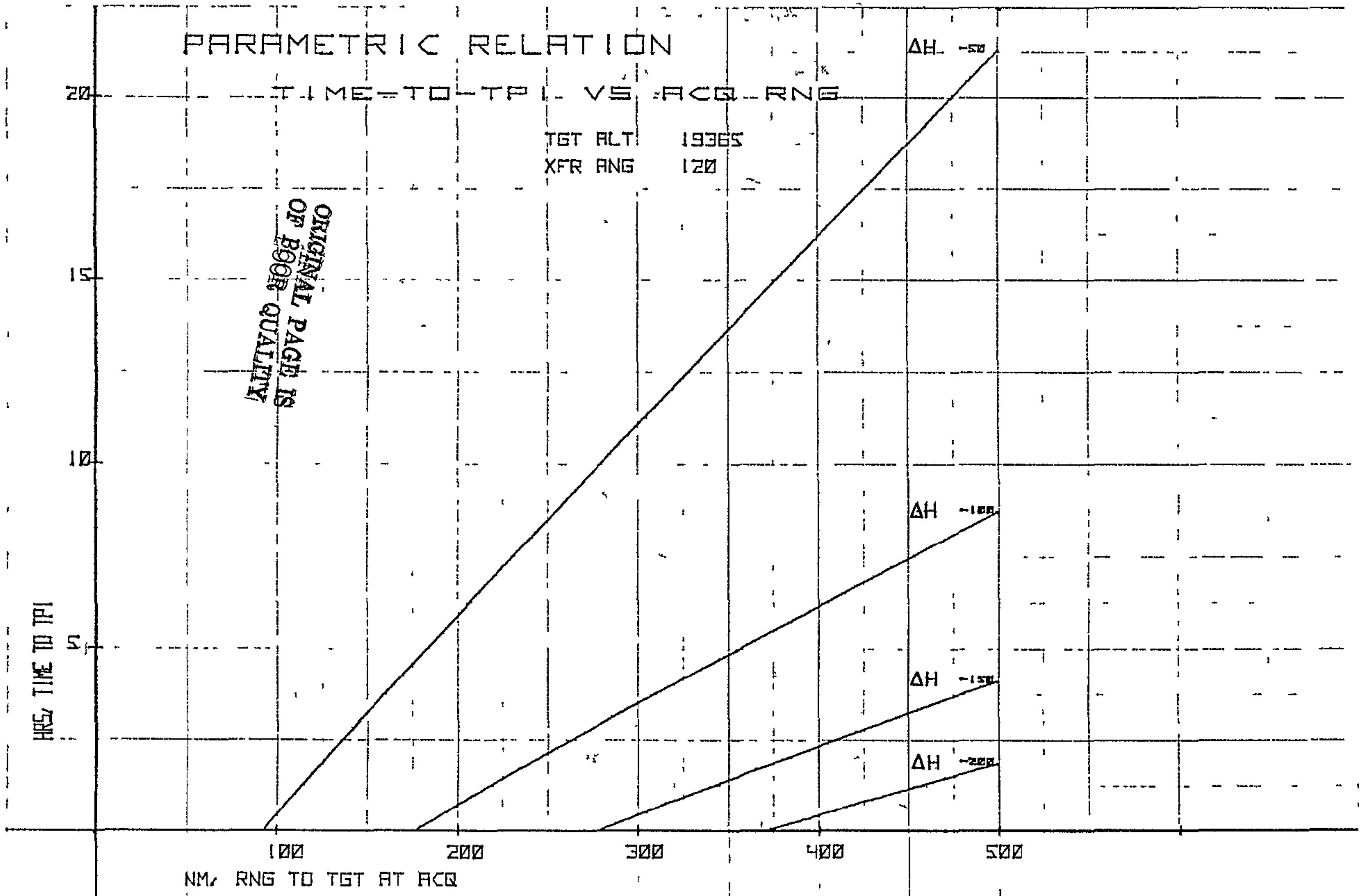

Figure 7.2 4-22 Parametric Relation Between Acquisition Range and Time to TPI for 120 Degree Transfers from Various ΔH at 19365 NMI Altitude

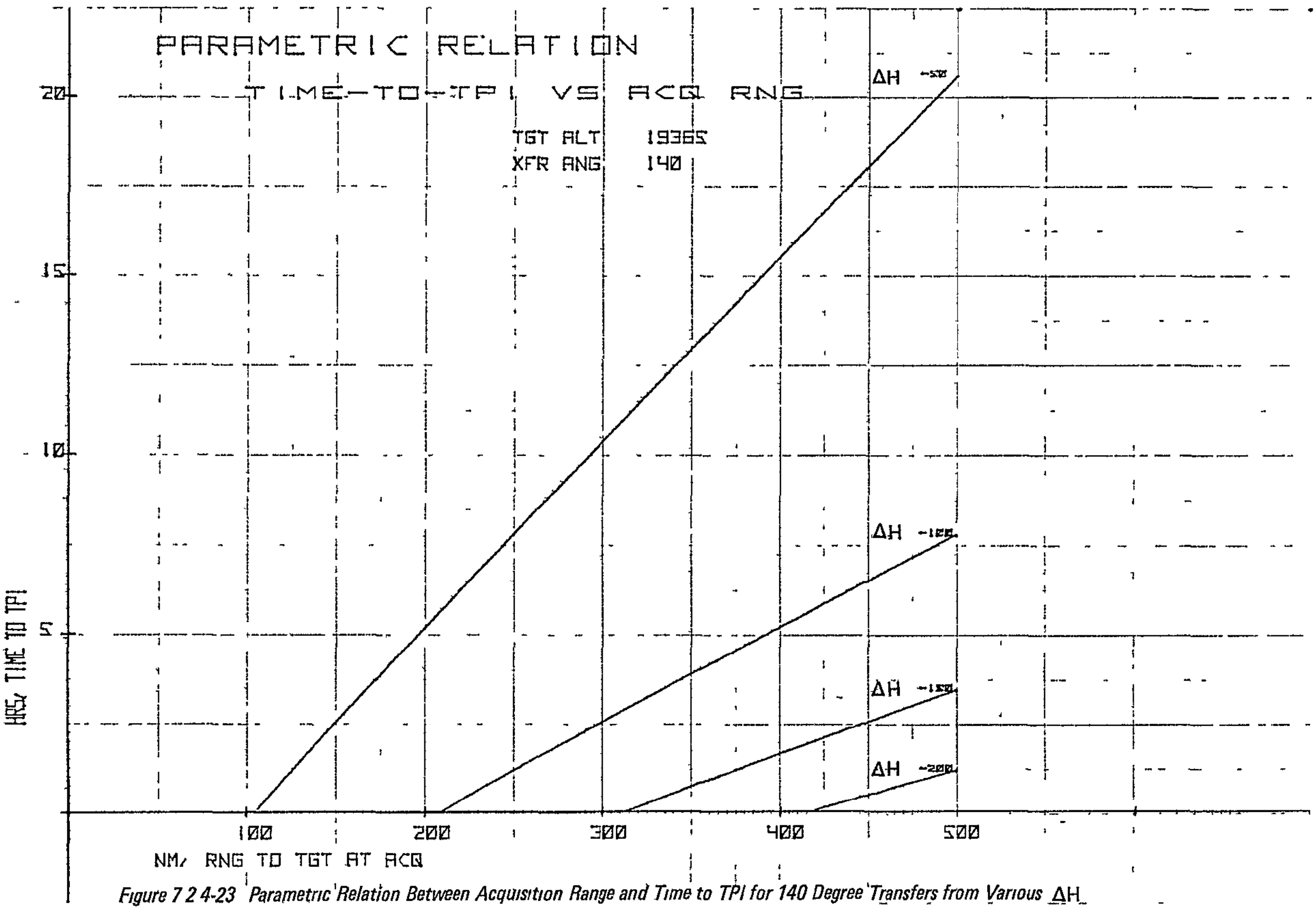

Figure 7 2 4-23 Parametric Relation Between Acquisition Range and Time to TPI for 140 Degree Transfers from Various ΔH at 19365 NMI Altitude

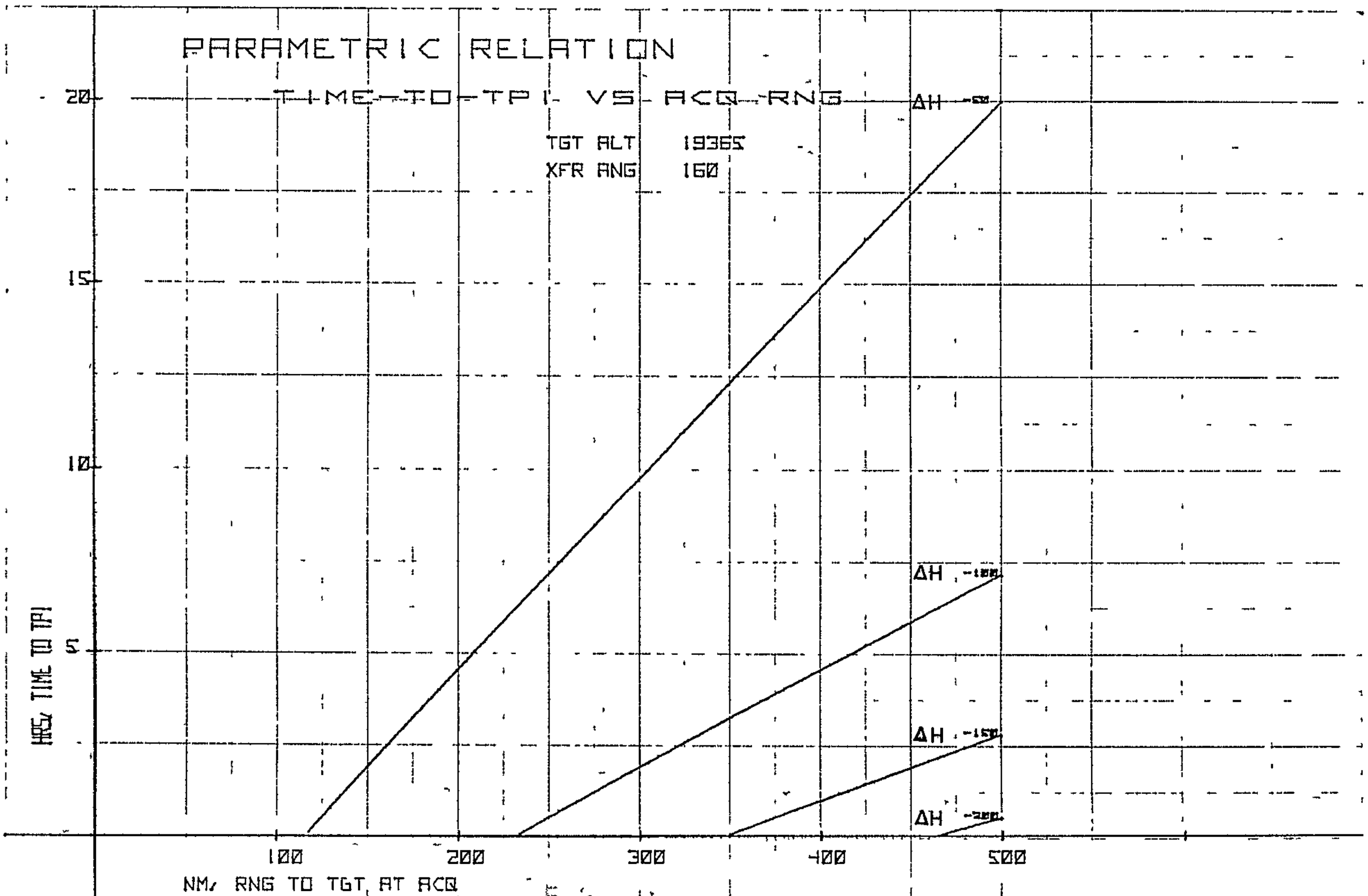

Figure 7 2 4-24 Parametric Relation Between Acquisition Range and Time to TPI for 160 Degree Transfers from Various ΔH at 19365 NMI Altitude

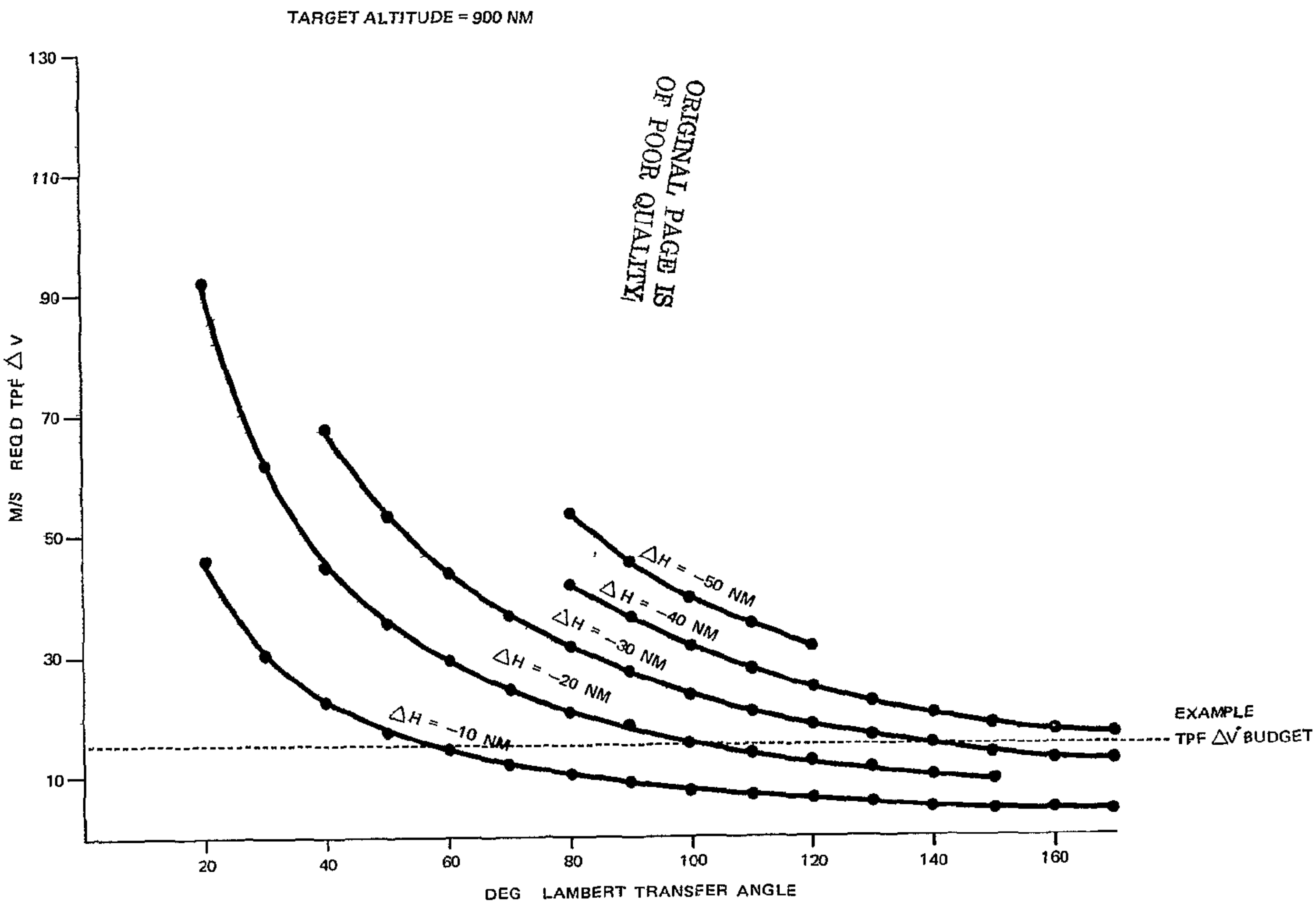

Figure 7 2 4-25 Parametric Relation Between TPF Velocity Change and Optimal Transfer Arc Length at 900 NMI Altitude

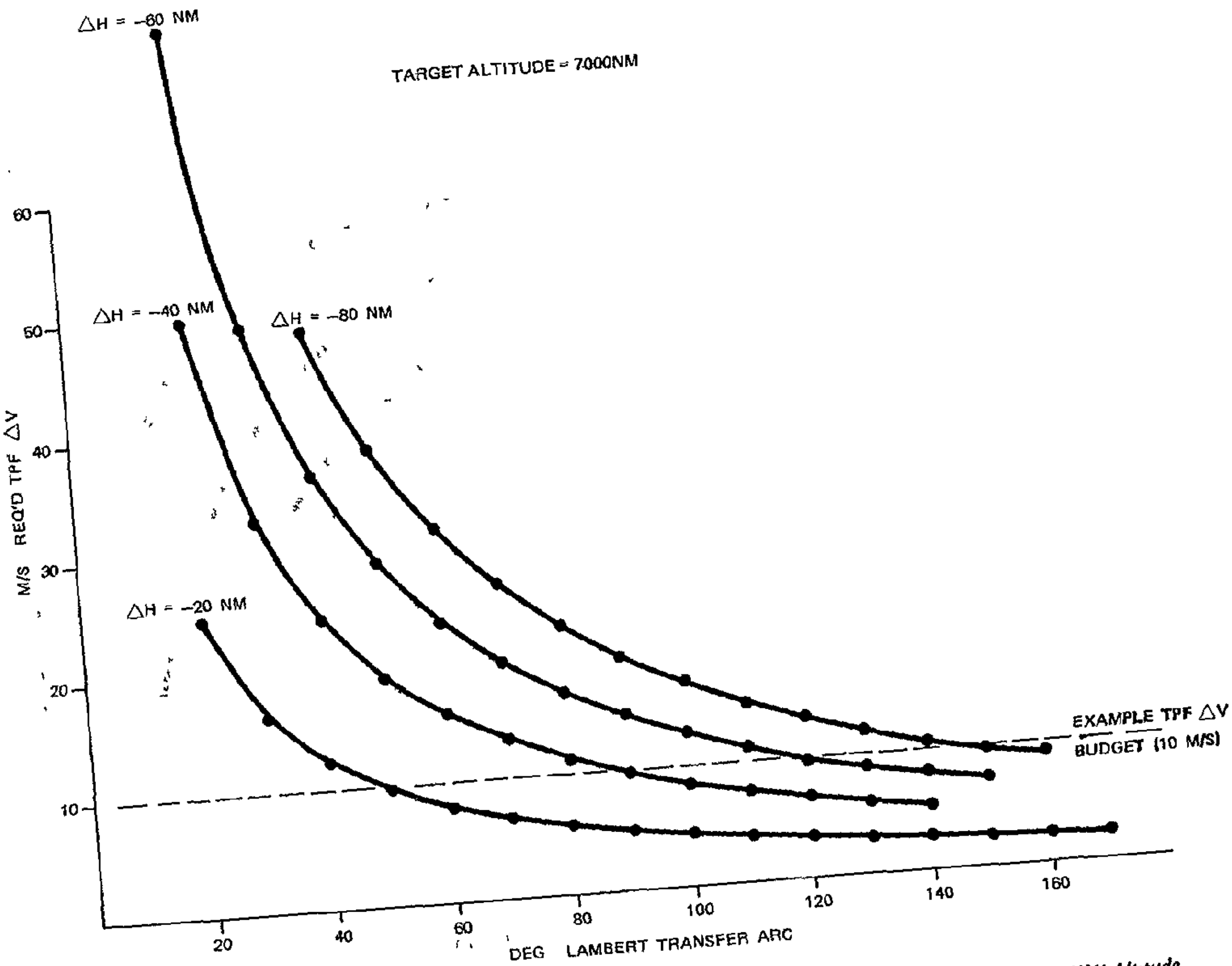

Figure 7 2 4-26 Parametric Relation Between Required TPF Velocity Change and Optimal Transfer Arc Length at 7000 NMI Altitude

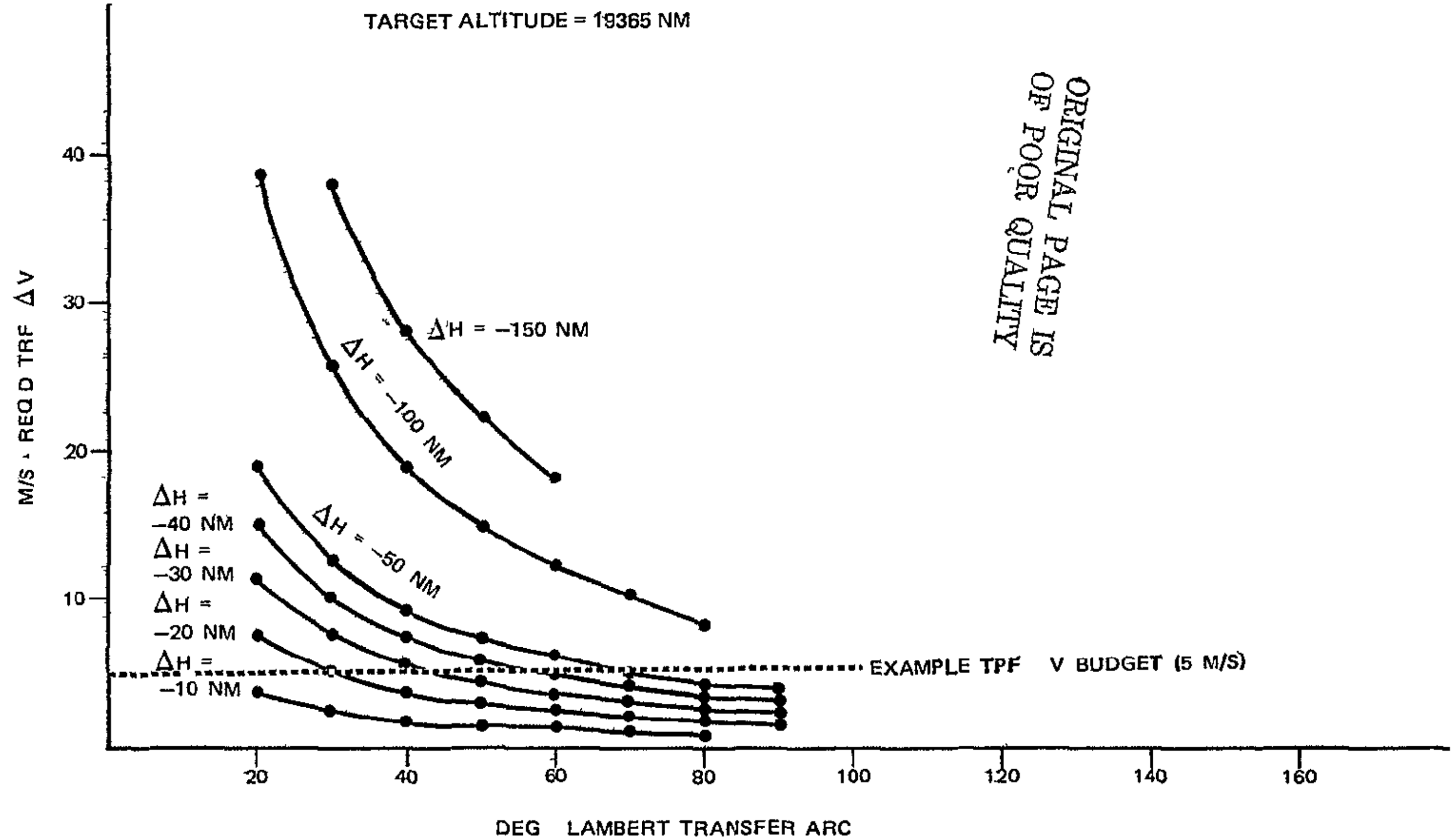

Figure 7 2 4-27 Parametric Relation Between TPF Velocity Change and Optimal Transfer Arc Length at 19365 NMI Altitude

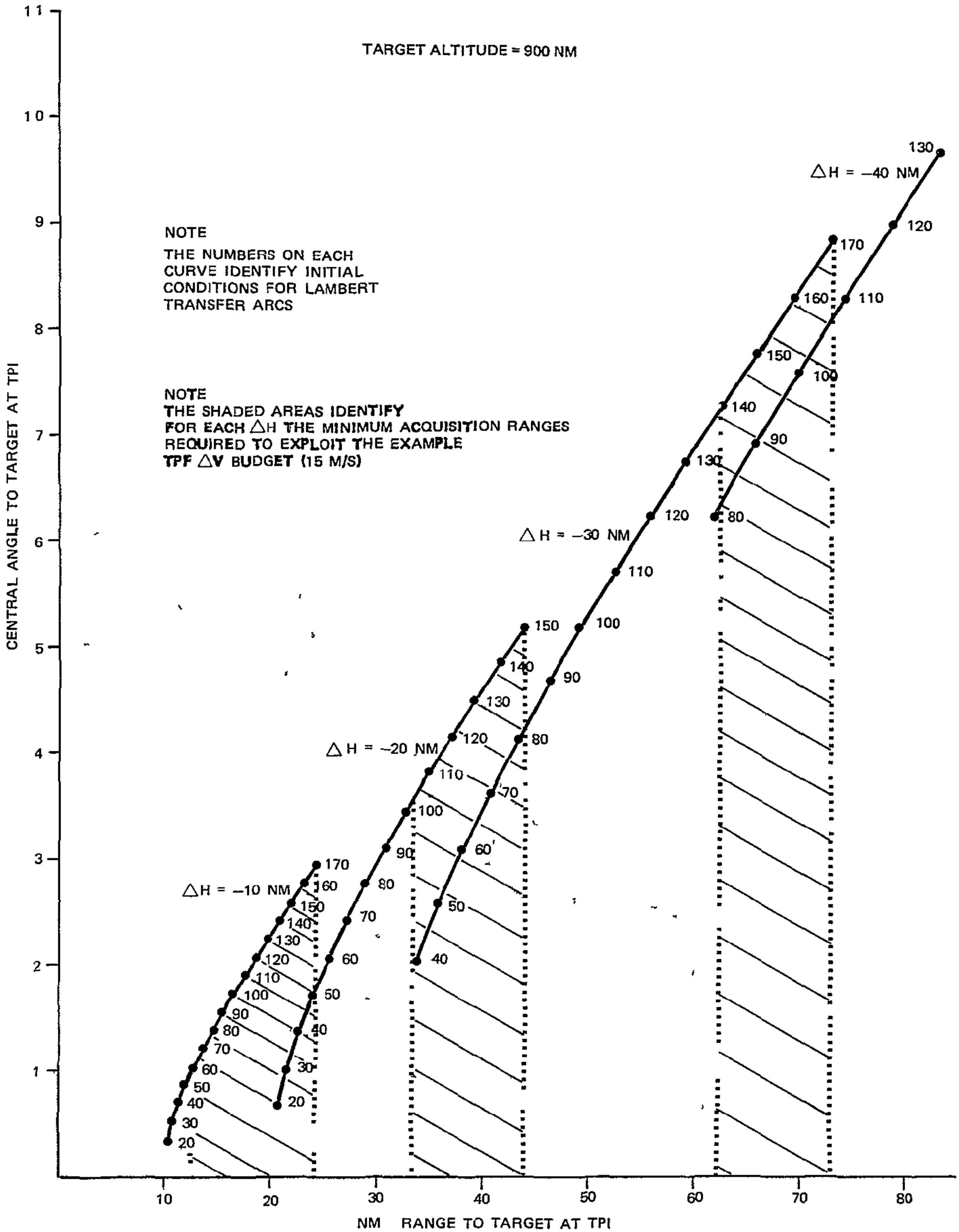

Figure 7 2 4-28 Parametric Relation Between Range to Target at TPI and Optimal Transfer Angle

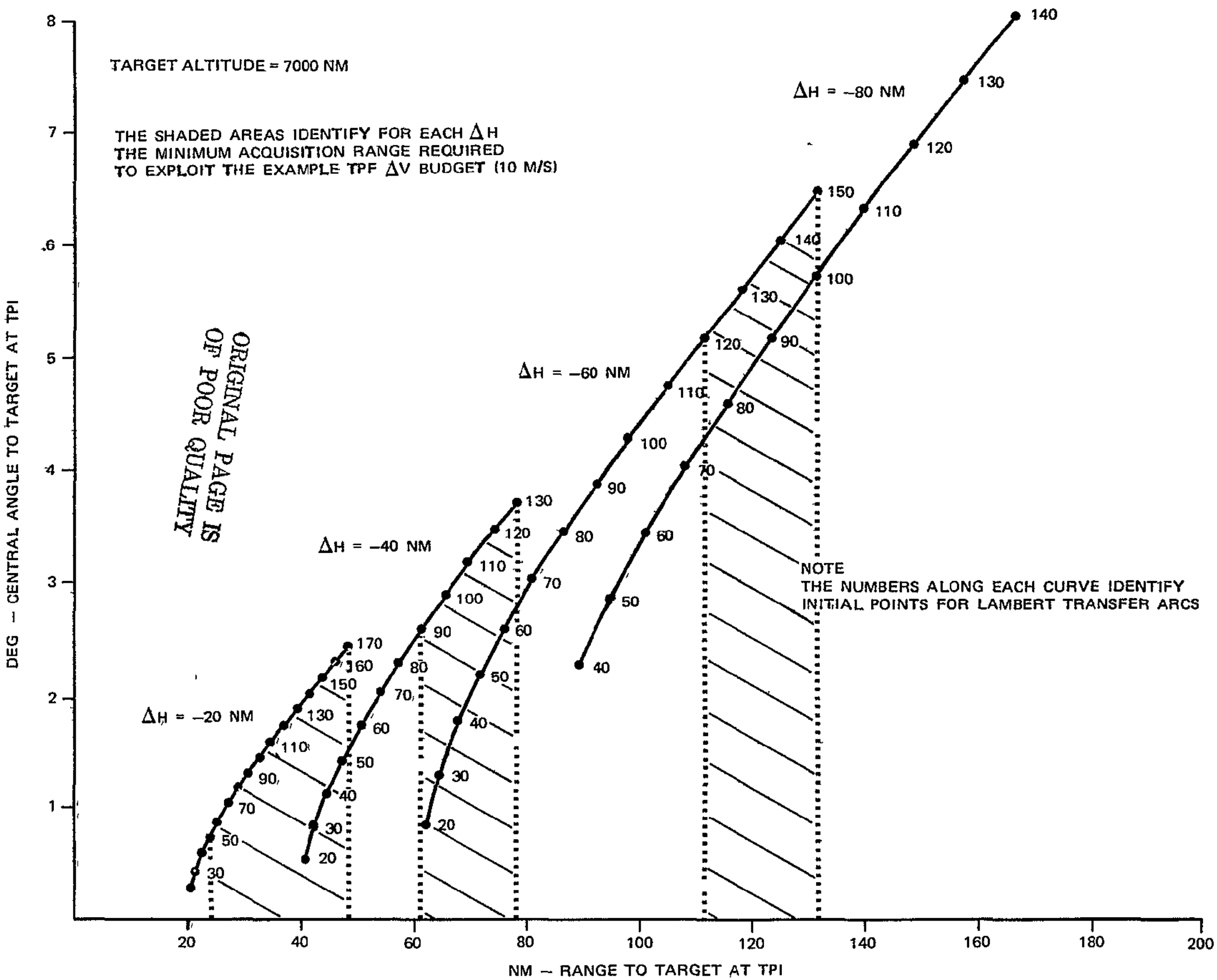

Figure 7 2 4-29 Parametric Relation Between Range to Target at TPF and Optimal Transfer Angle

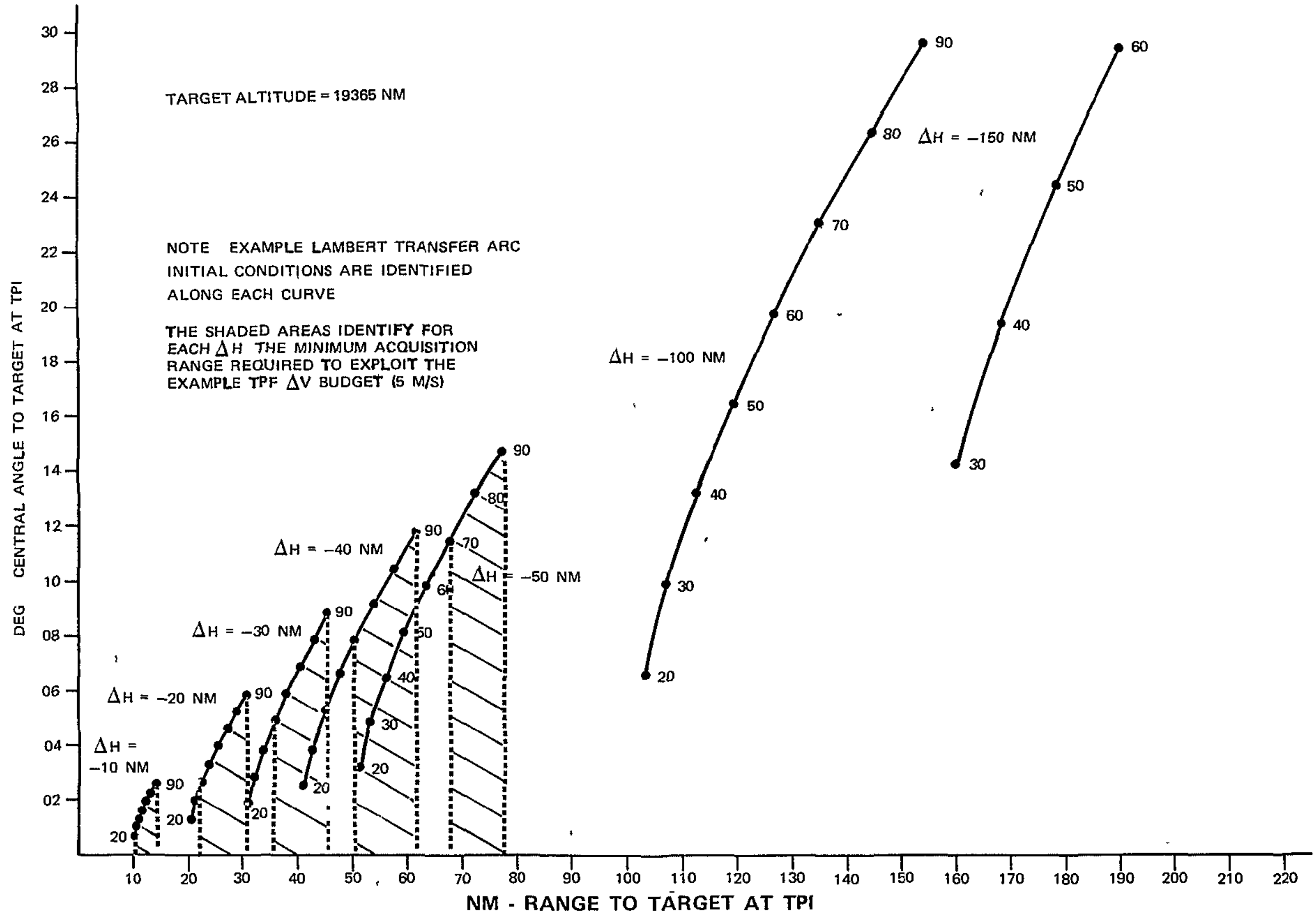

Figure 7 2 4-30 Parametric Relation Between Range to Target at TPF and Optimal Transfer Angle

The relation between any impulse budget and a candidate rendezvous tracker acquisition range is important and should be reviewed each time values for either parameter are being evaluated Reiterating the earlier caution, the Lambert solutions employed in developing these relations were optimal,, requiring a minimum impulse with approximately equal impulse requirements at TPI and TPF Non-optimal transfers require somewhat more impulse and exhibit unequal impulse requirements at TPI and TPF by may lower the acquisition range required for a particular transfer without significantly increasing the TPF impulse requirement The side speeds at braking gates may also be significantly affected

The example braking gates, shown in Figures 7 2 4-31 through 7 2 4-36, illustrate the complex relation between orbital-dynamics parameters and target-relative line-of-sight closing speed and side speed Each initial starting orbit, as defined by differential height, seems to have a best transfer angle, i e., one yielding a minimum side speed, at each gate. But that transfer arc may not be attainable within the impulse budget constraint In the absence of a definition of how much side speed is too much, these charts serve to characterize the transfers previously constrained by impulse and acquisition range The more general relationships between range and the closing and side speeds are illustrated in Figures 7 2 4-37 athrough 7 2 4-58 The range at which side speed is a minimum varies as a function of transfer arc indicating fixed-range braking gates may not be the best braking philosophy

The closing speeds, directed along the instantaneous line of sight, in all cases were inversely related to the transfer angles Closing speed tended to decrease with range but significantly only for cases of height differentials of 20 nmi or less and at target altitudes of 900 and 7000 nmi (Figure 7 2 4-37, -39 and -43) These indicated that braking gates could be placed economically as near as 1 Km to the Spacecraft

Side speed, the resultant speed normal to the line of sight, was not simply related to the transfer angle Because an unsigned magnitude was plotted, some of the curves folded back at the abscissa (Figure 7 2 4-38) That does not significantly impair the meaning of the curves. The goal was identification of transfer angles yielding low side-speed components during the final 10 Km (5 4 nmi.) of closure so that the dynamics to be encountered during braking could be understood.

For the cases at a target altitude of 900 nmi the minima occured for only one transfer angle at each differential height 60 degree transfer yielded the minimum at a range of 5 Km for a ΔH of -10 nmi , 100 degrees at 2 Km for ΔH of -20 nmi , and 170 degrees at 1-5 Km for ΔH of -30 nmi The sidespeeds for transfers at a target altitude of 7000 nmi behaved differently as the transfer angle was varied (Figure 7 2-7-44, -46, and -48) When the Tug closed from differential heights of -20 nmi and -40 nmi , all the transfers plotted yielded sidespeed minimum of less than 0 025 m/s but at different ranges The 90 and 100 degree transfers from a ΔH of -20 nmi seem to yield the lowest average side speed For a ΔH of -40 nmi , the same two transfer angles yielded side speeds below 0 05 m/s for ranges between 7 and 3 Km, but transfers of 120 degrees from both -20 nmi and -40 nmi height differentials exhibited continuously diminishing sidespeed until minima occurred at ranges of 1 Km The lowest side speed for an initial height difference of -60 nmi also occurred during the closure along the 120 degree arc

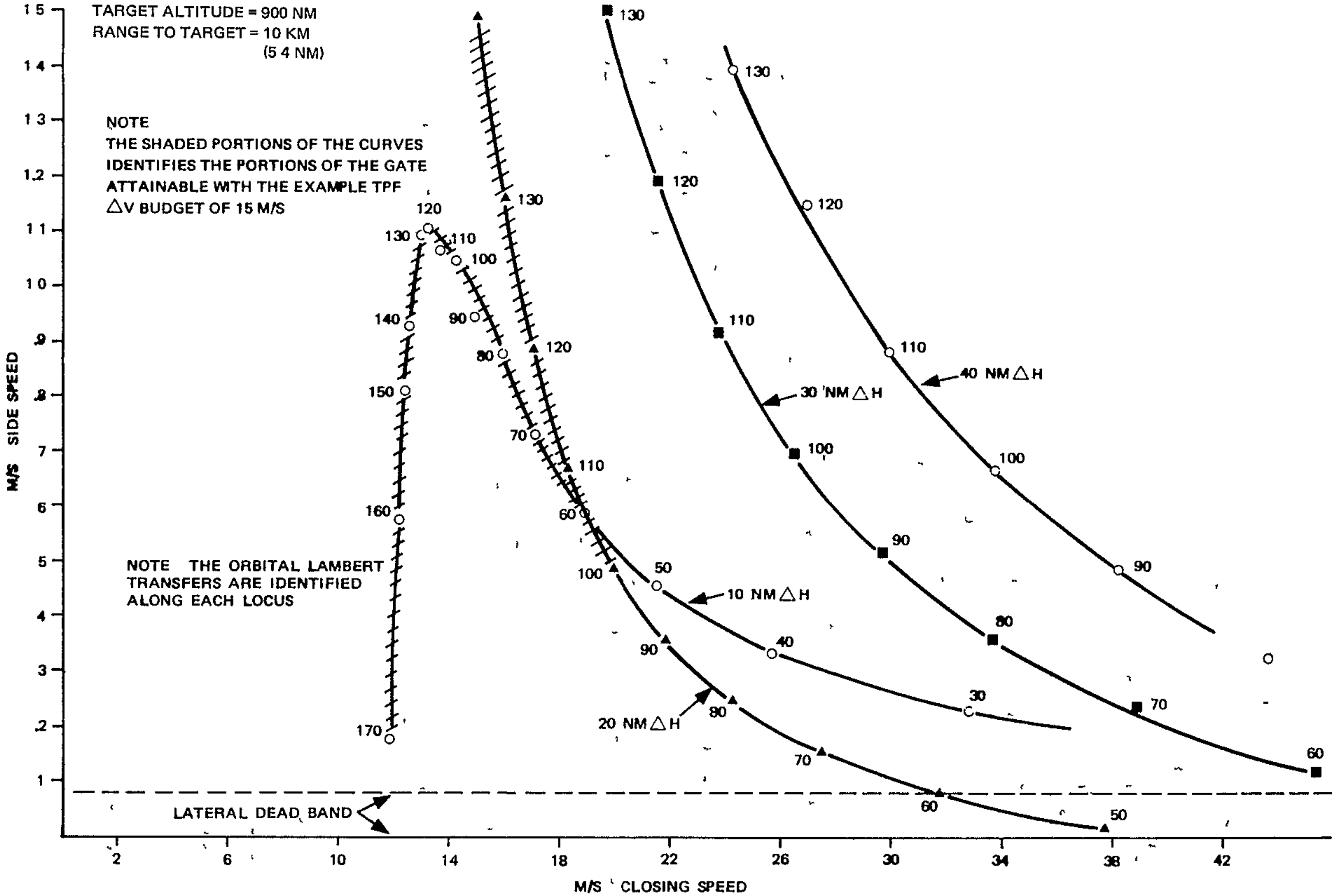

Figure 7 2 4-31 Parametric Relation Between Transfer Angle and Closing and Side Speeds at an Example Braking Gate

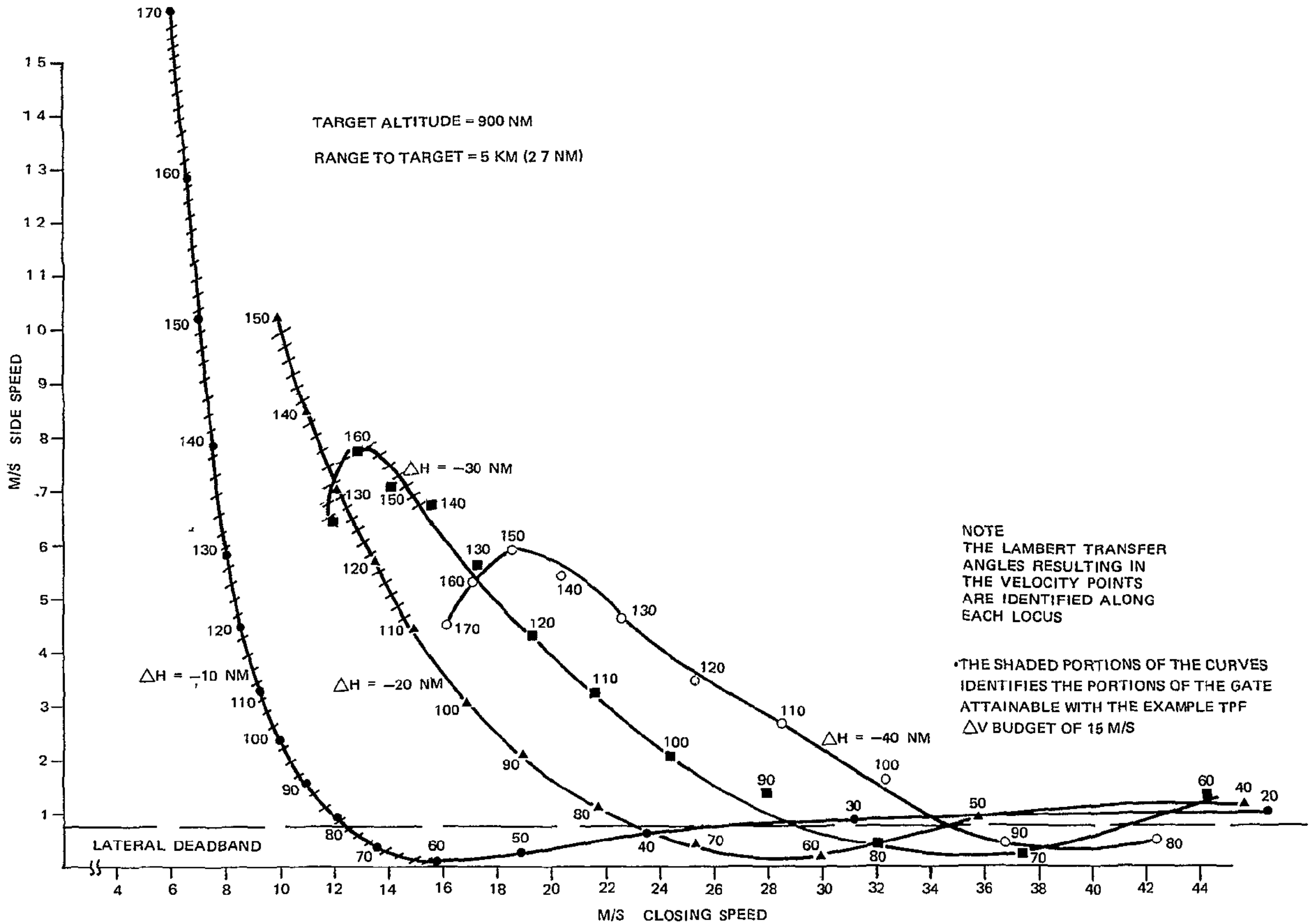

Figure 7 2 4-32 Parametric Relation Between Optimal Transfer Angle and Closing and Side Speeds at an Example Braking Gate

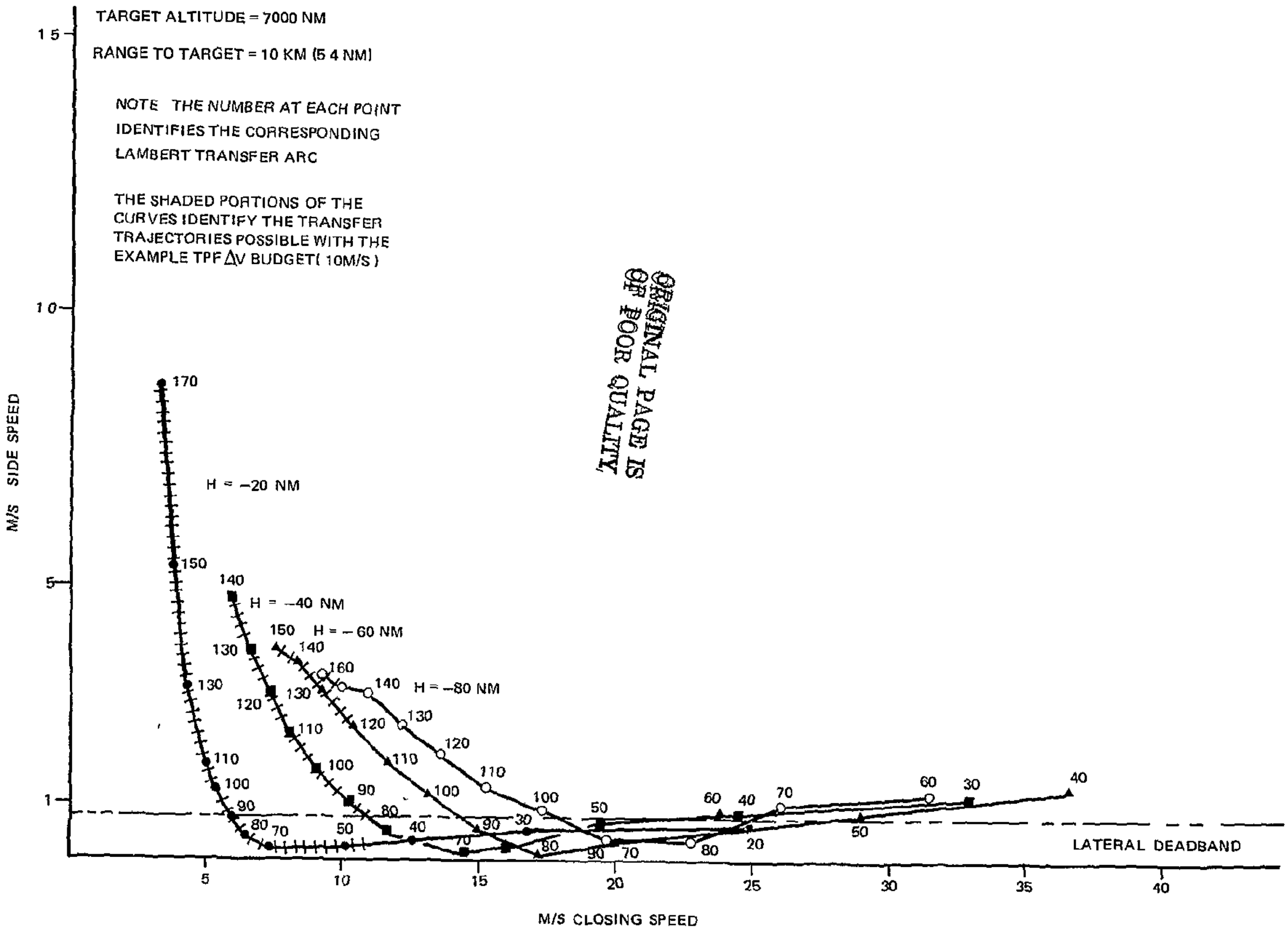

Figure 7 2 4-33 Parametric Relation Between Optimal Transfer Angle and Closing and Side Speeds at an Example Braking Gate

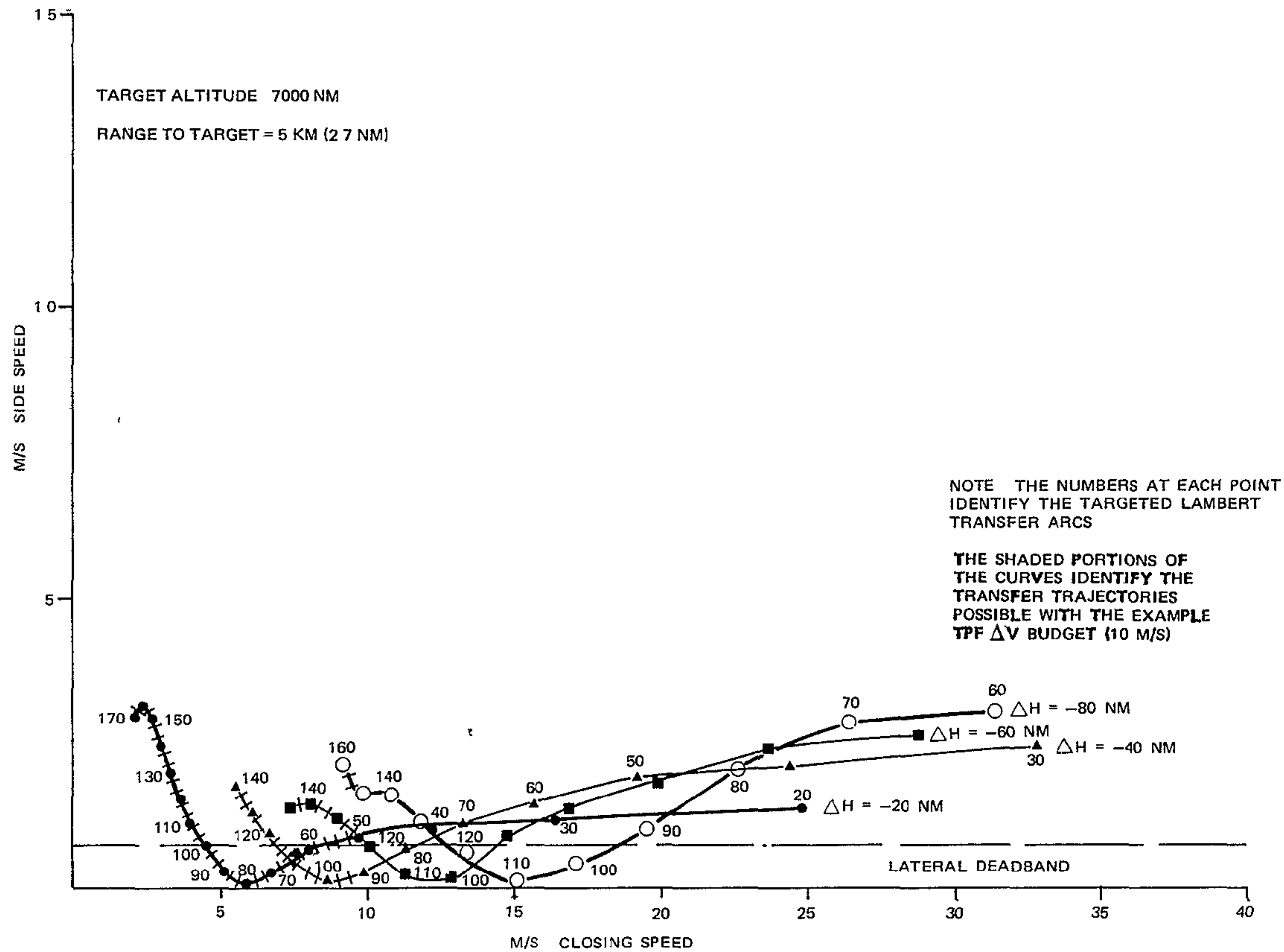

Figure 7 2 4-34 Parametric Relation Between Optimal Transfer Angle and Closing and Side Speeds at an Example Braking Gate

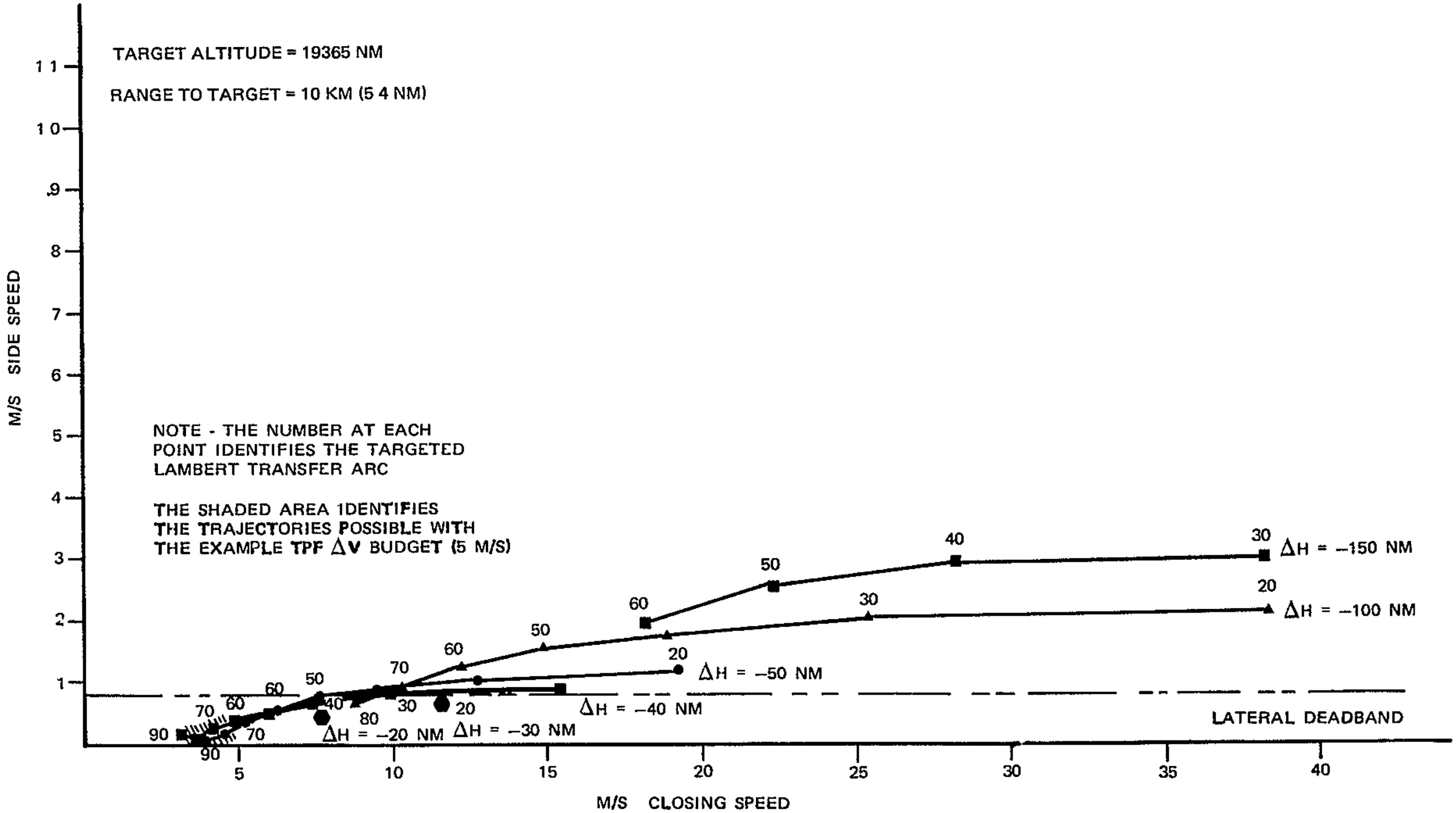

Figure 7 2 4-35 Parametric Relation Between Optimal Transfer Angle and Closing and Side Speeds at an Example Braking Gate

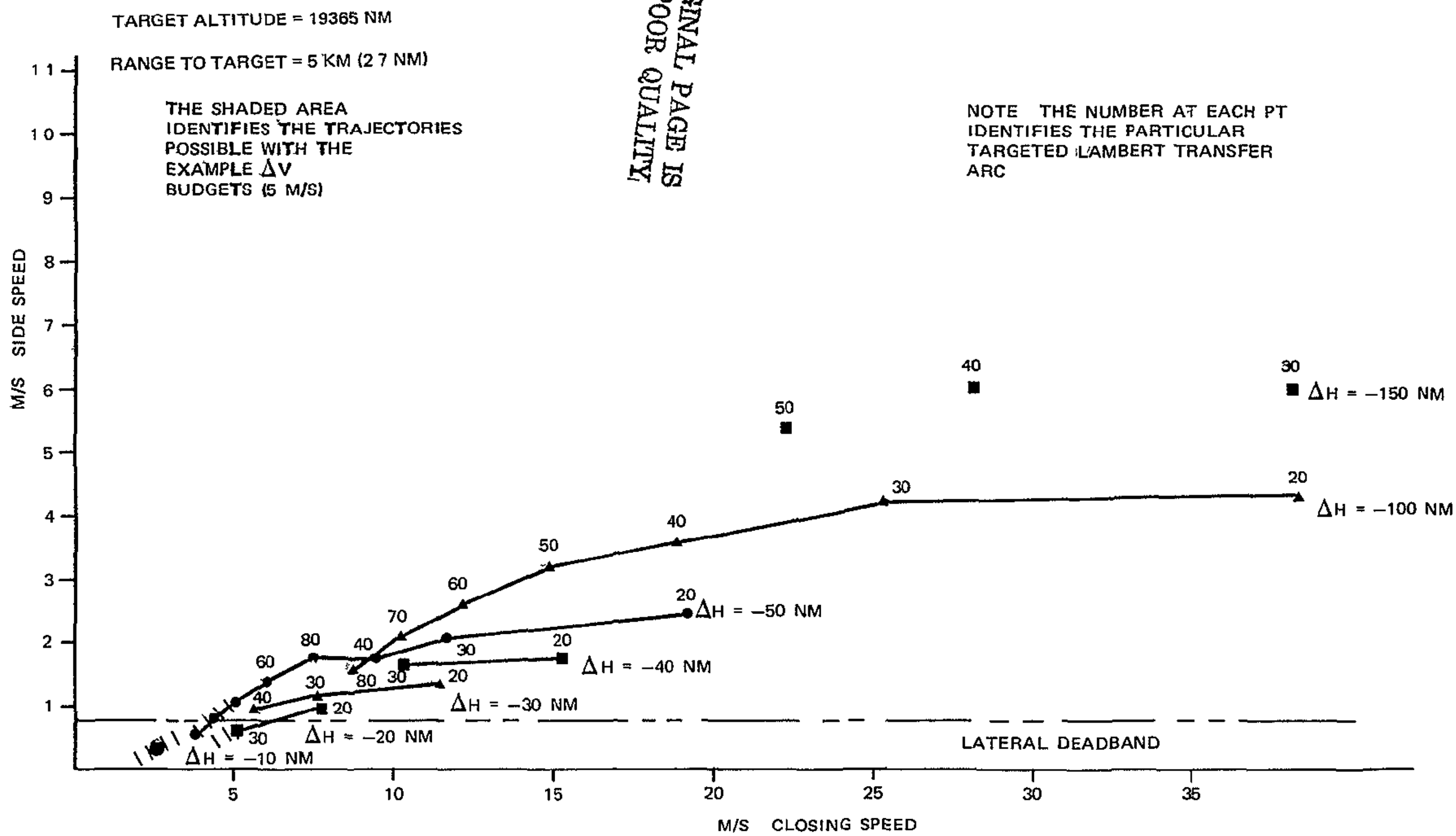

Figure 7 2 4-36 Parametric Relation Between Optimal Transfer Angle and Closing and Side Speed at an Example Braking Gate

TARGET ALTITUDE = 900 NMI

TUG INITIAL ΔH = -10 NMI

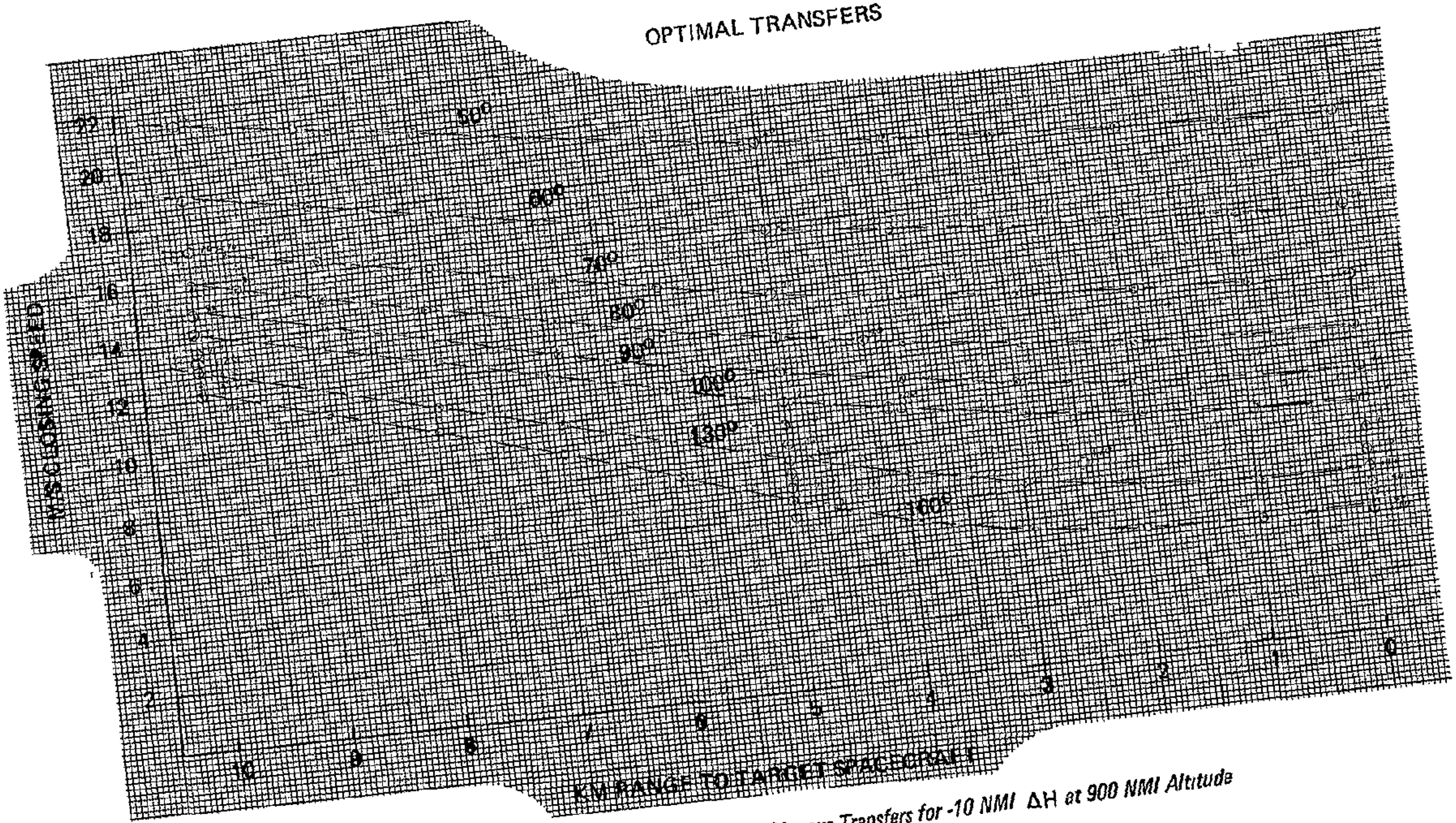

Figure 7 2 4 37 Parametric Relation Between Closing Speed and Range for Various Transfers for -10 NMI ΔH at 900 NMI Altitude

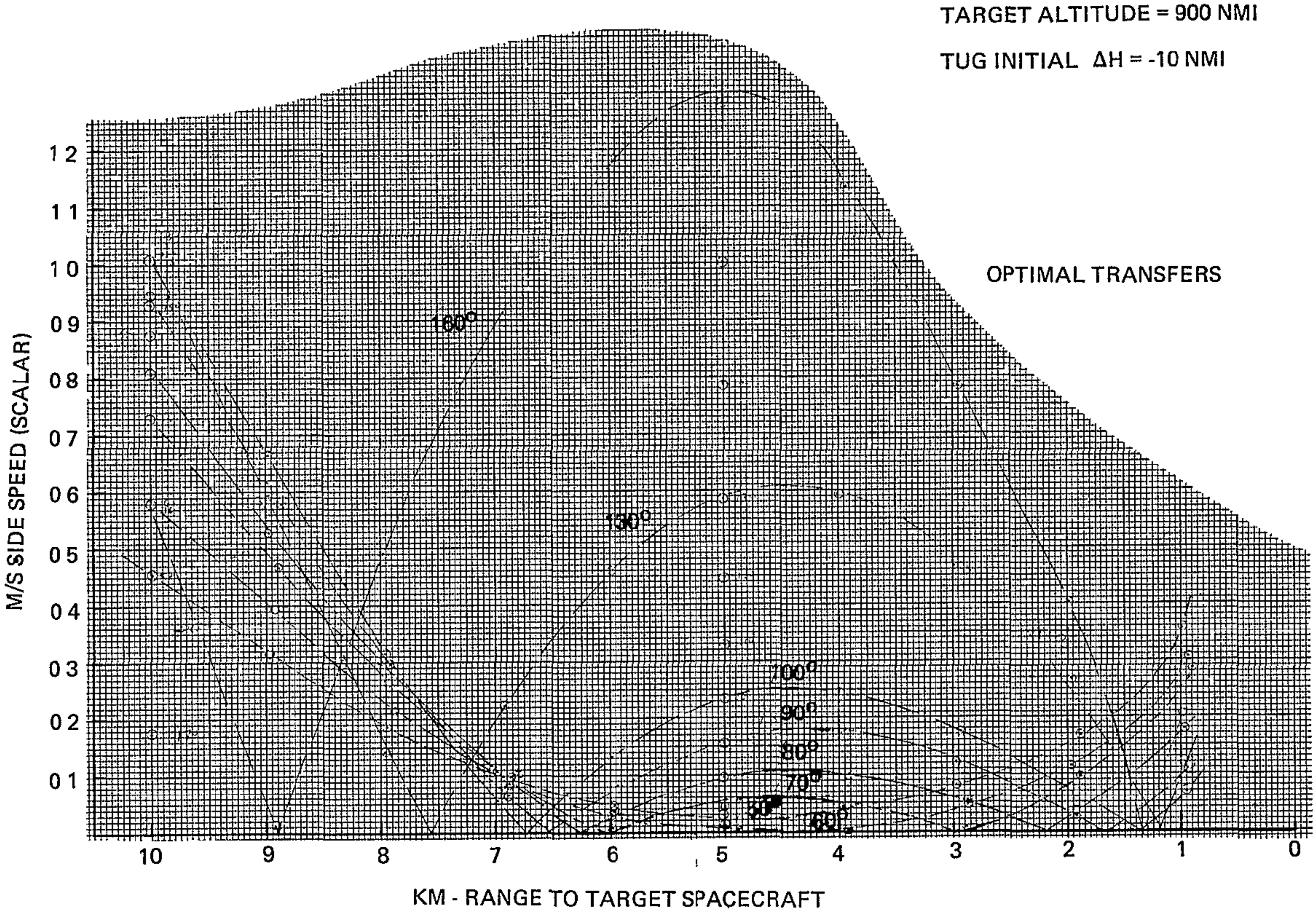

Figure 7 2 4-38 Parametric Relation Between Side Speed and Range for Various Transfers from -10 NMI ΔH at 900 NMI Altitude

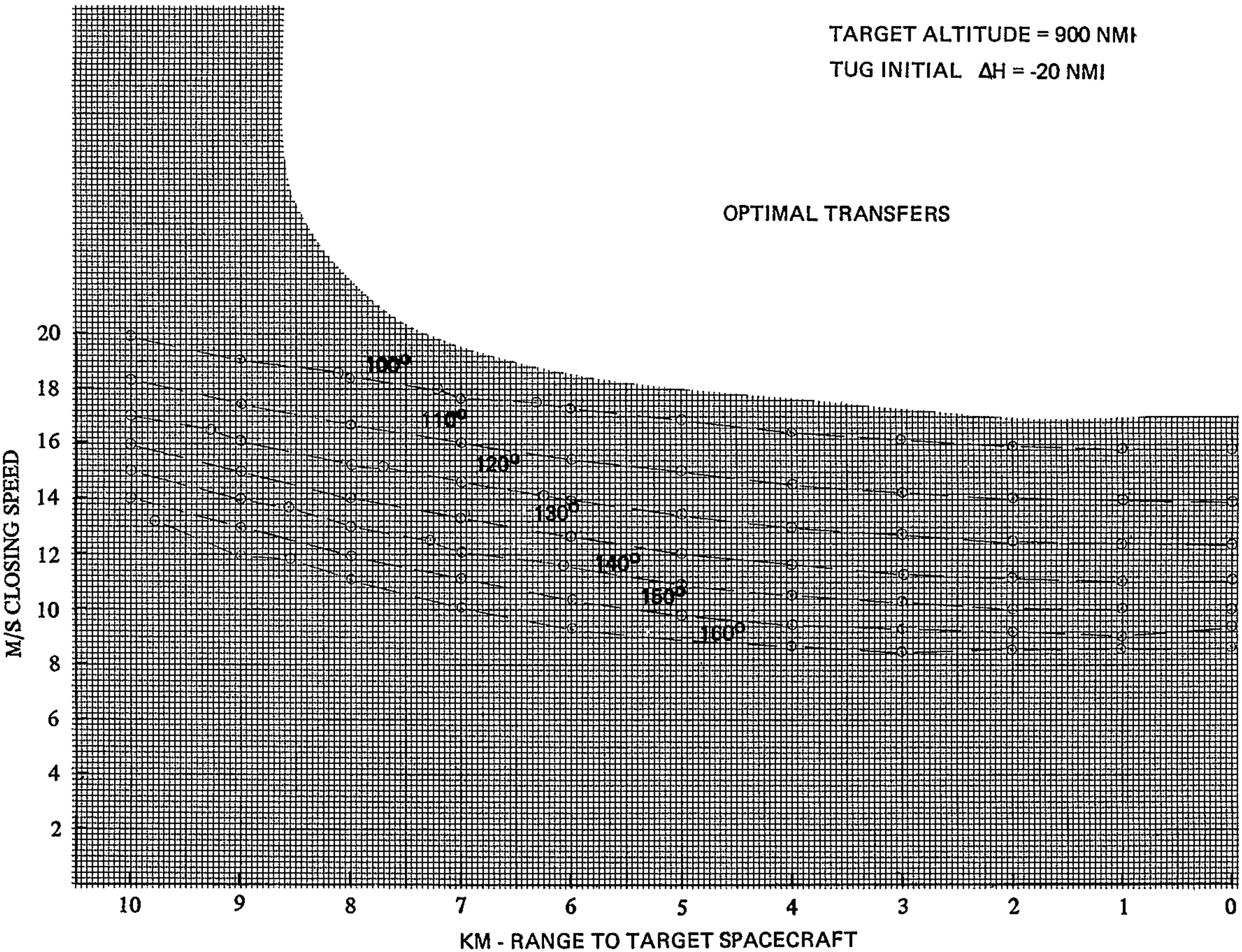

Figure 7.2 4-39. Parametric Relation Between Closing Speed and Range for Various Transfers from -20 NMI ΔH' at 900 NMI Altitude

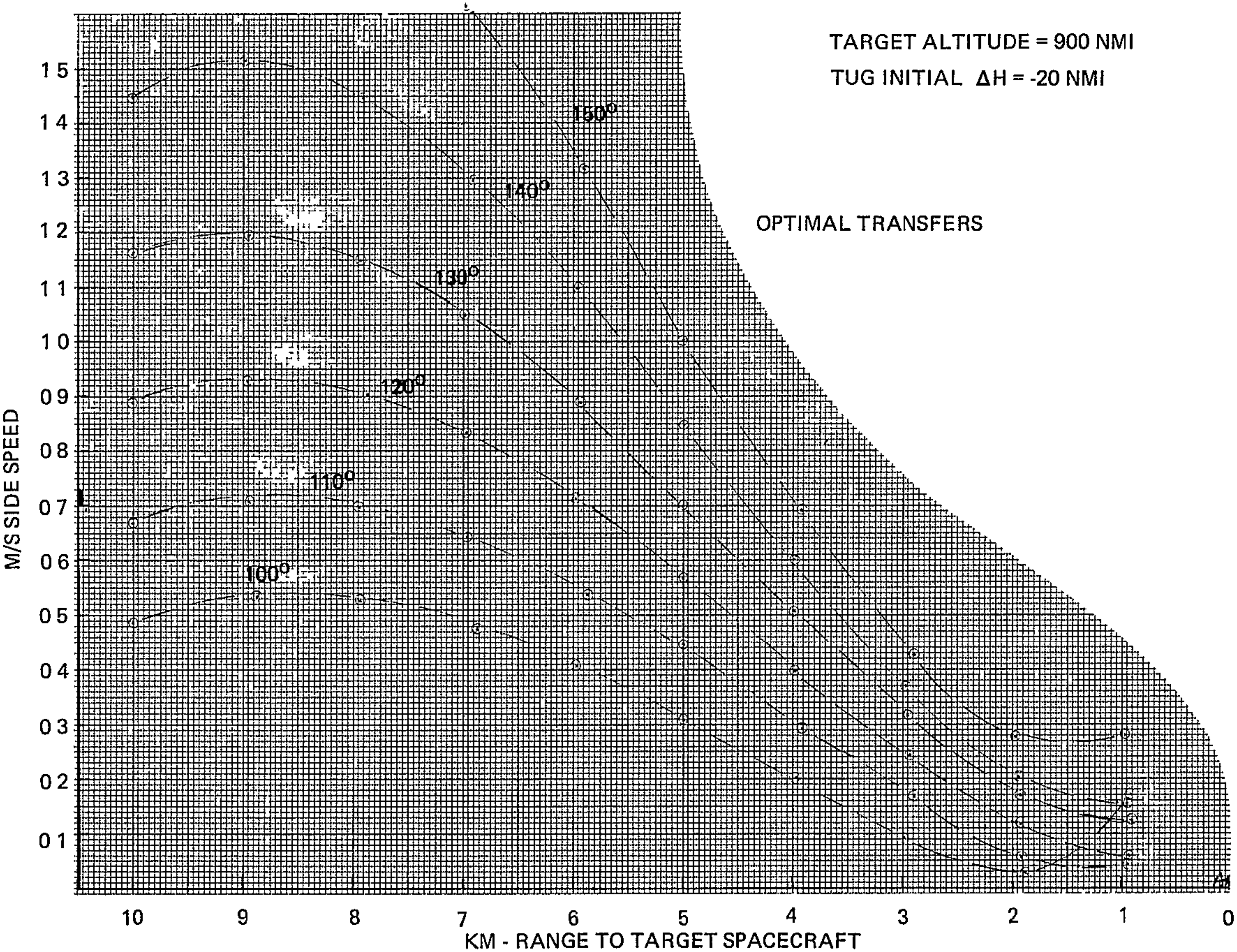

Figure 7 2 4-40 Parametric Relation Between Side Speed and Range for Various Transfers from -20 NMI ΔH at 900 NMI Altitude

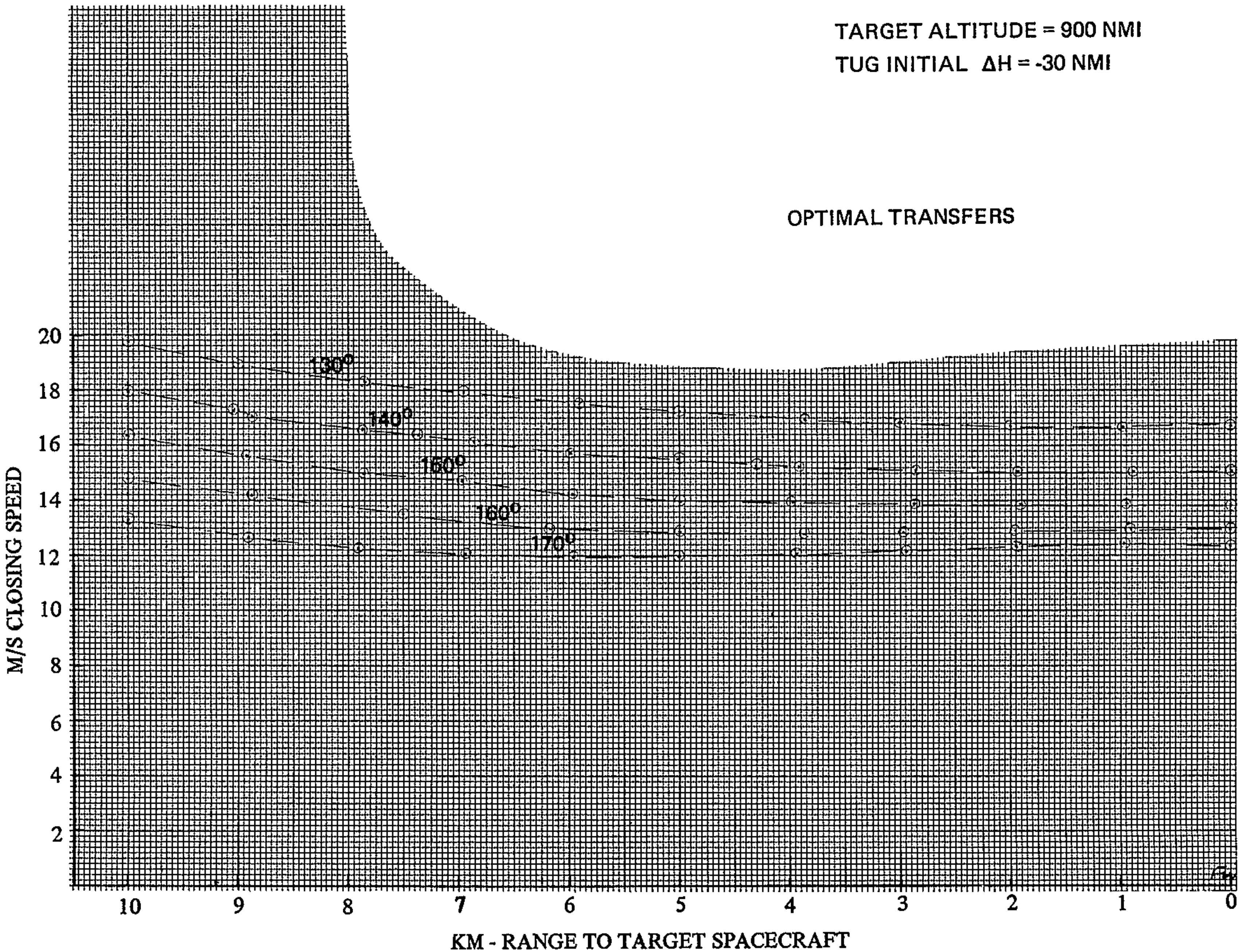

Figure 7.2 4-41 Parametric Relation Between Closing Speed and Range for Various Transfers from -30 NMI ΔH at 900 NMI ALTITUDE

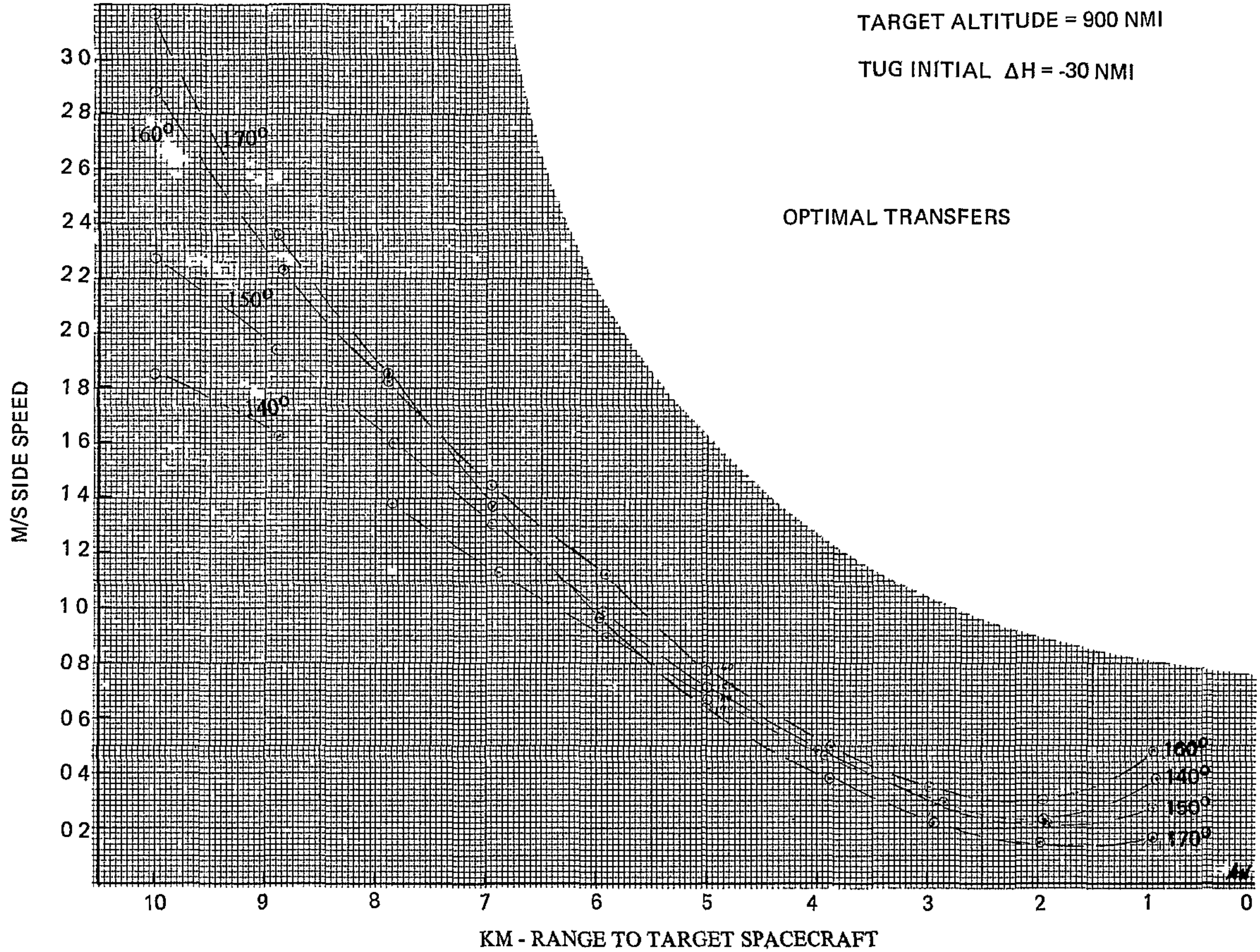

Figure 7 2 4-42 Parametric Relation Between Side Speed and Range for Various Transfers from -30 NMI ΔH at 900 NMI Altitude

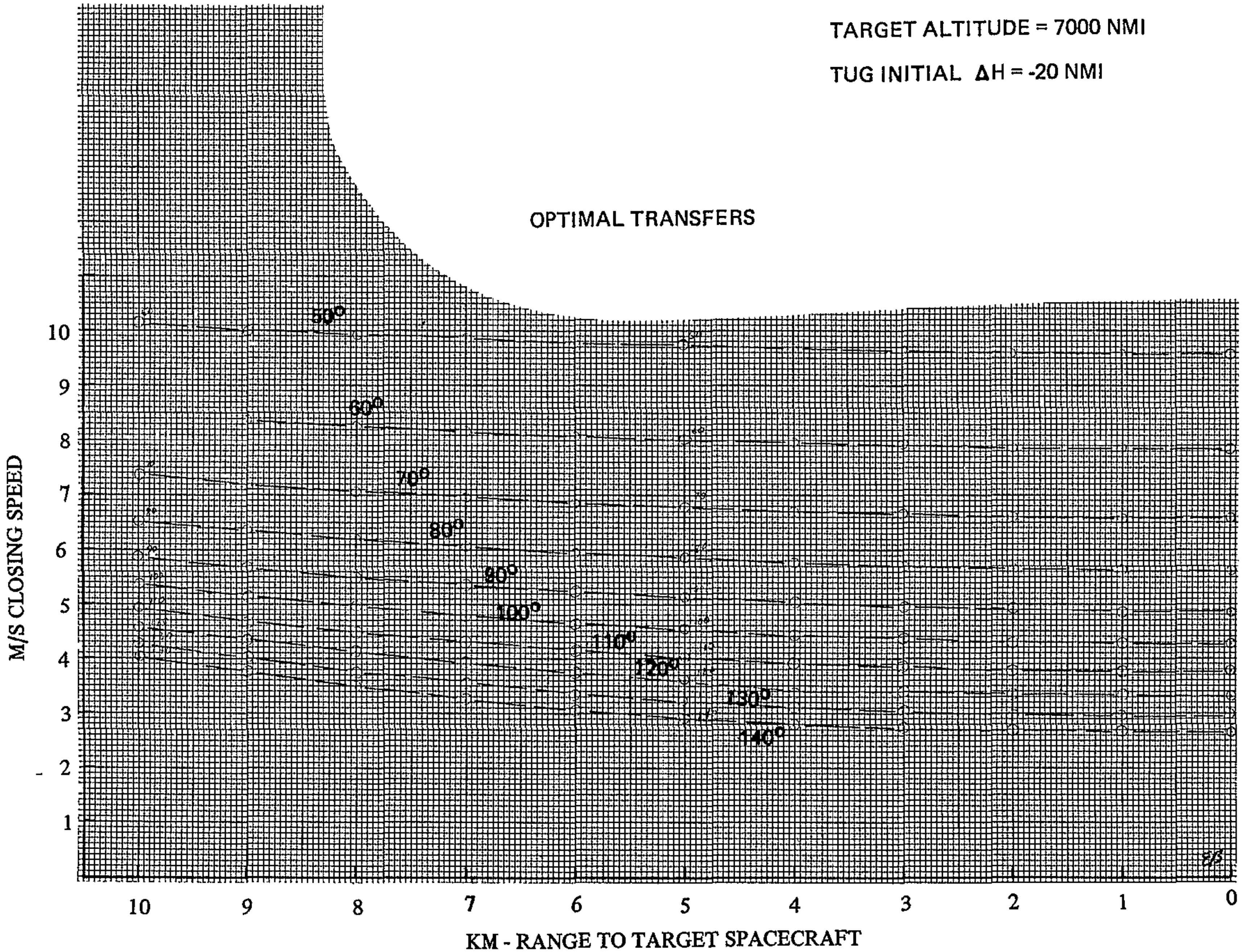

Figure 7 2 4-43 Parametric Relation Between Closing Speed and Range for Various Transfers from -20 NMI ΔH at 7000 NMI Altitude

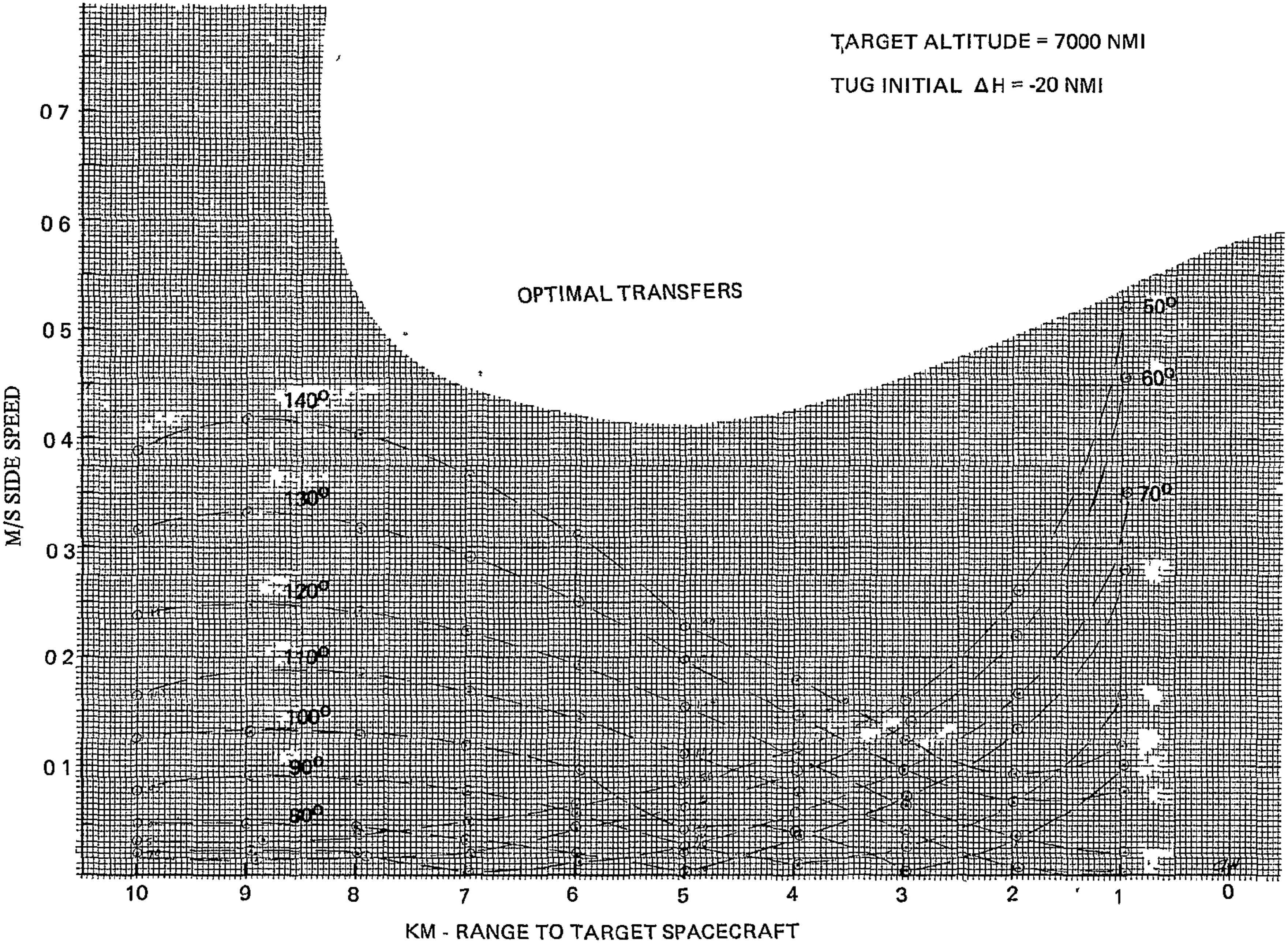

Figure 7 2 4-44 Parametric Relation Between Side Speed and Range for Various Transfers from -20 NMI ΔH at 7000 NMI Altitude

TARGET ALTITUDE = 7000 NMI

TUG INITIAL ΔH = -40 NMI

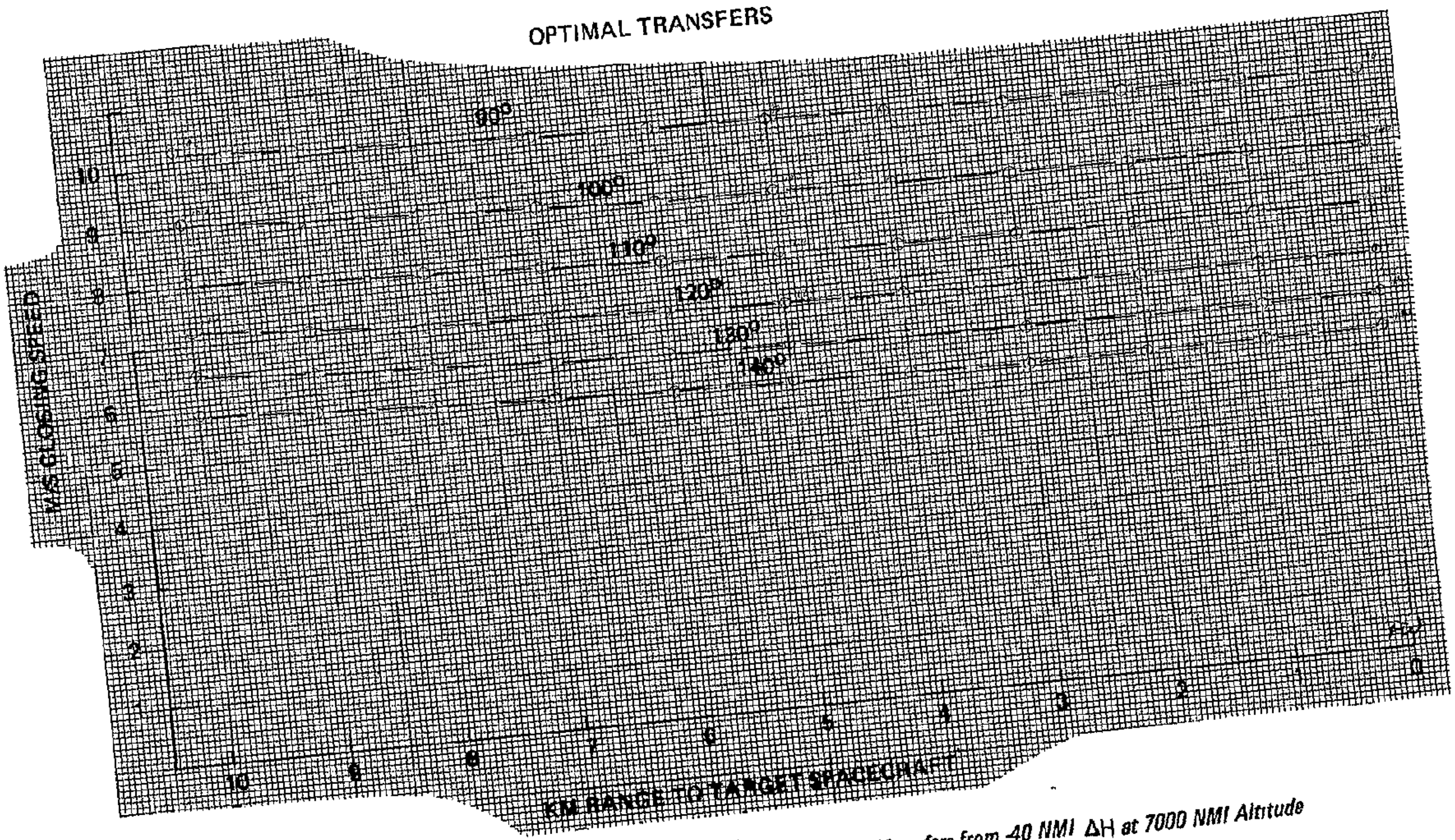

Figure 7 2 4-45. Parametric Relation Between Closing Speed and Range for Various Transfers from -40 NMI ΔH at 7000 NMI Altitude

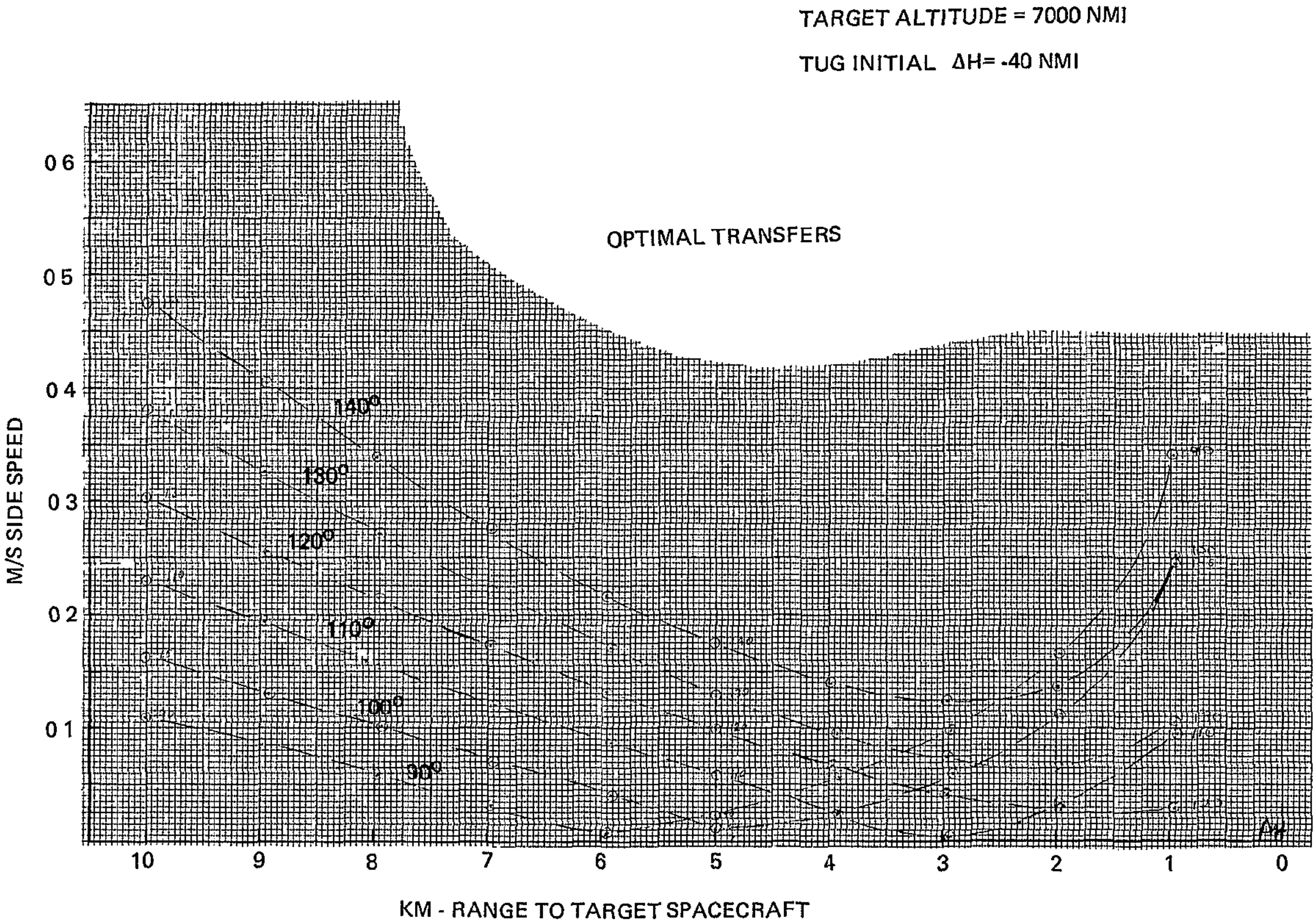

Figure 7.2 4-46 Parametric Relation Between Side Speed and Range for Various Transfers from -40 NMI ΔH at 7000 NMI Altitude

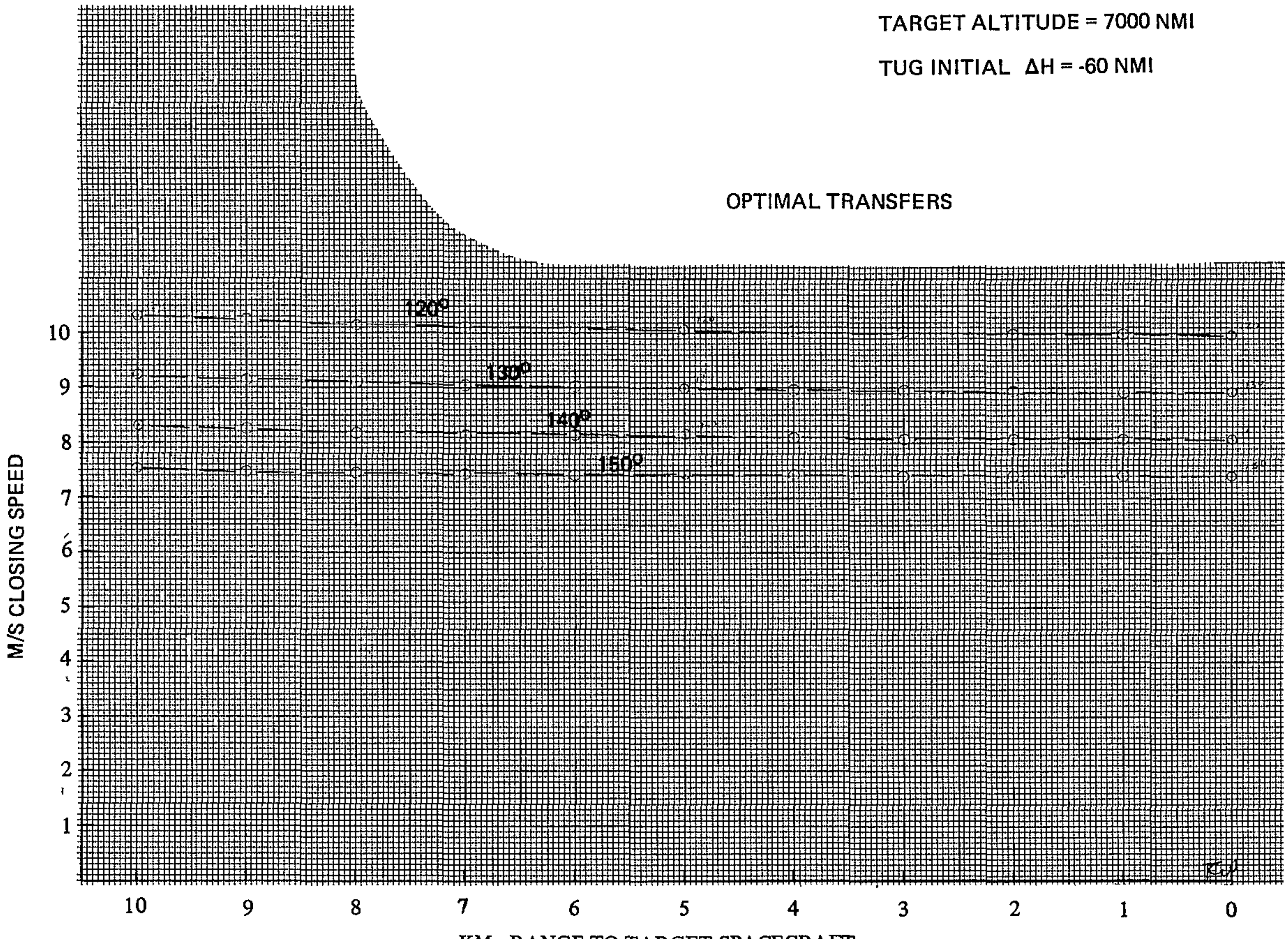

Figure 7 2 4-47. Parametric Relation Between Closing Speed and Range for Various Transfers from -60 NMI ΔH at 7000 NMI Altitude

TARGET ALTITUDE = 7000 NMI

TUG INITIAL ΔH = -60 NMI

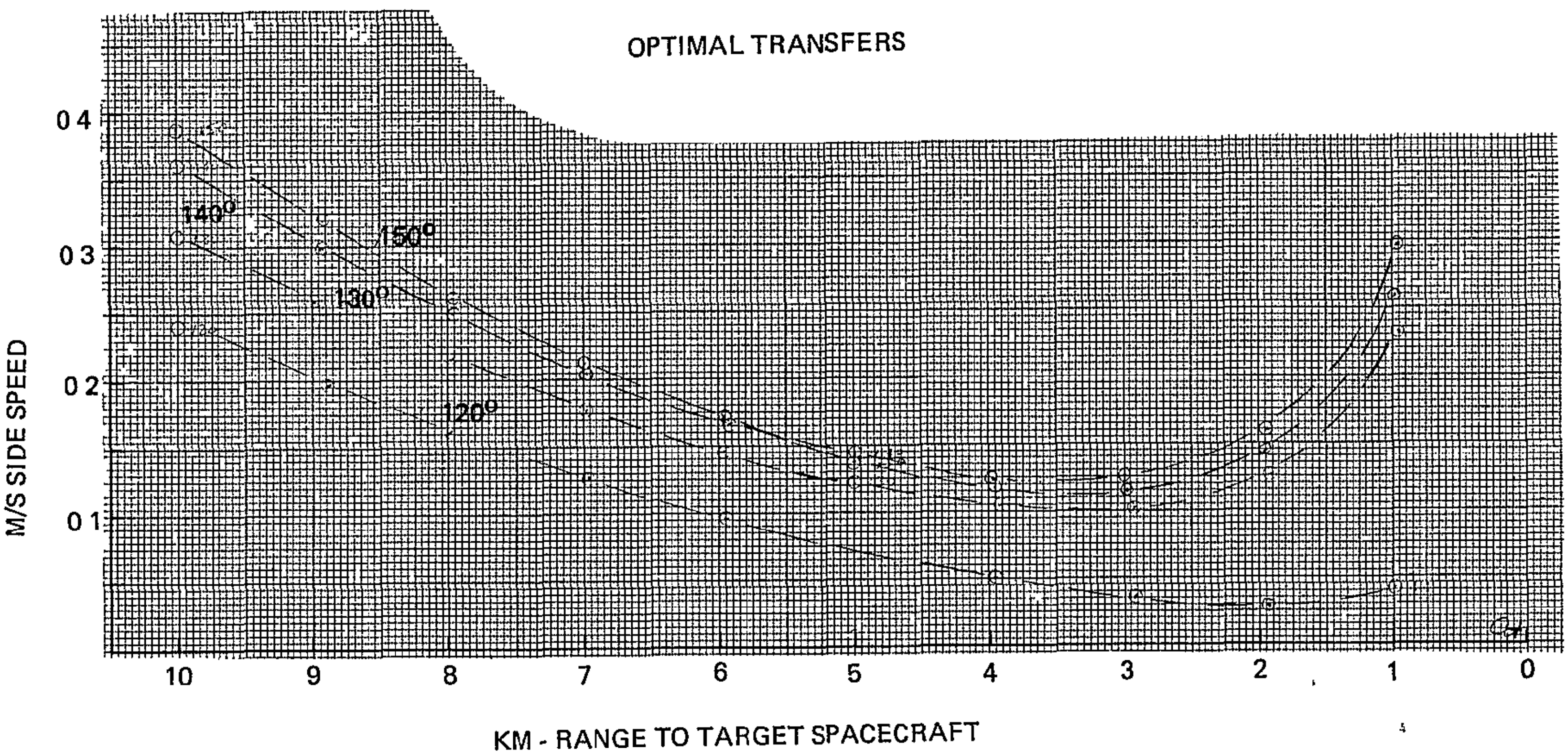

Figure 7 2 4-48 Parametric Relation Between Side Speed and Range for Various Transfers from -60 NMI ΔH at 7000 NMI Altitude

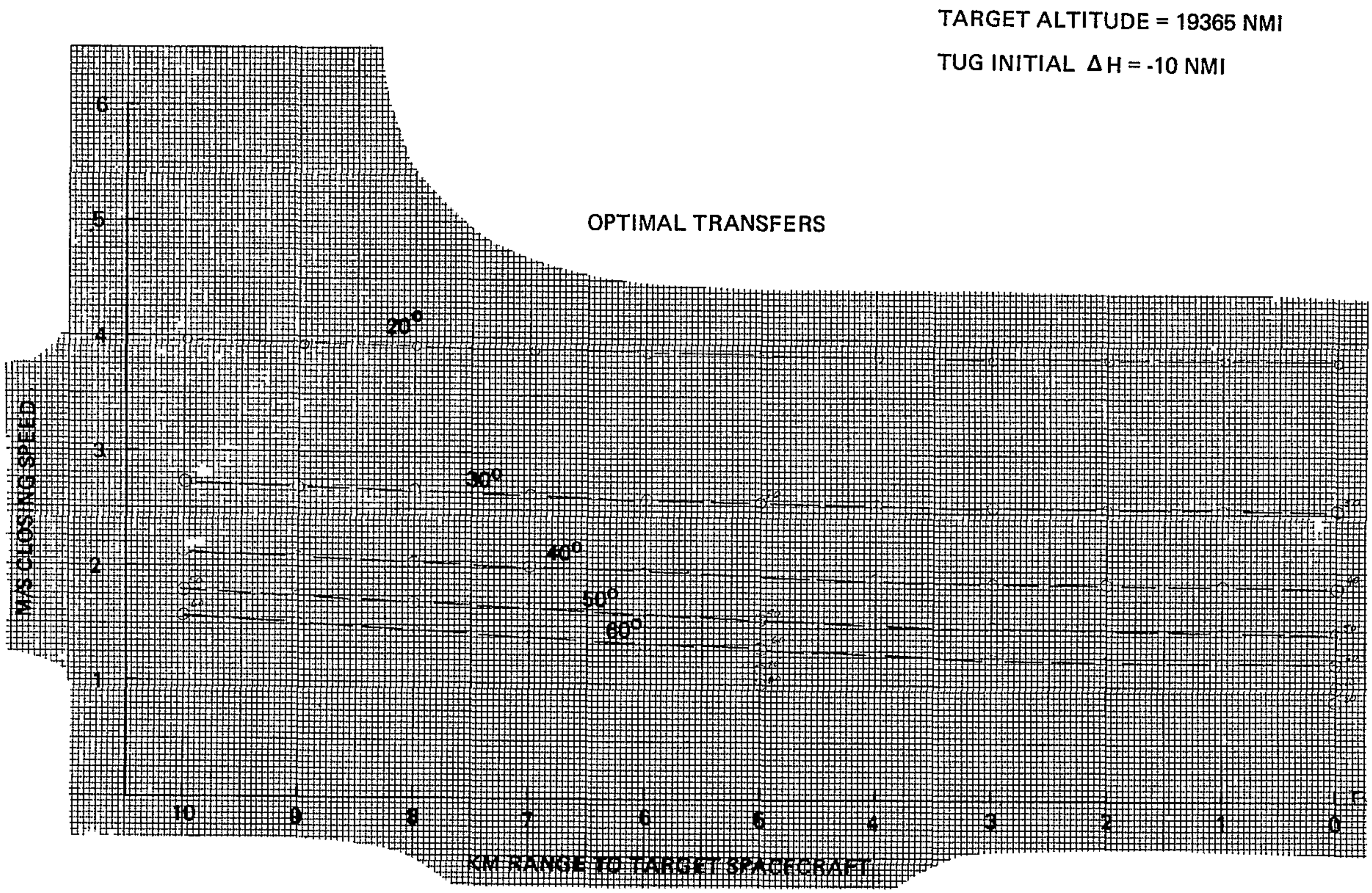

Figure 7 2 4-49 Parametric Relation Between Closing Speed and Range for Various Transfers from -10 NMI ΔH at 19365 NMI Altitude

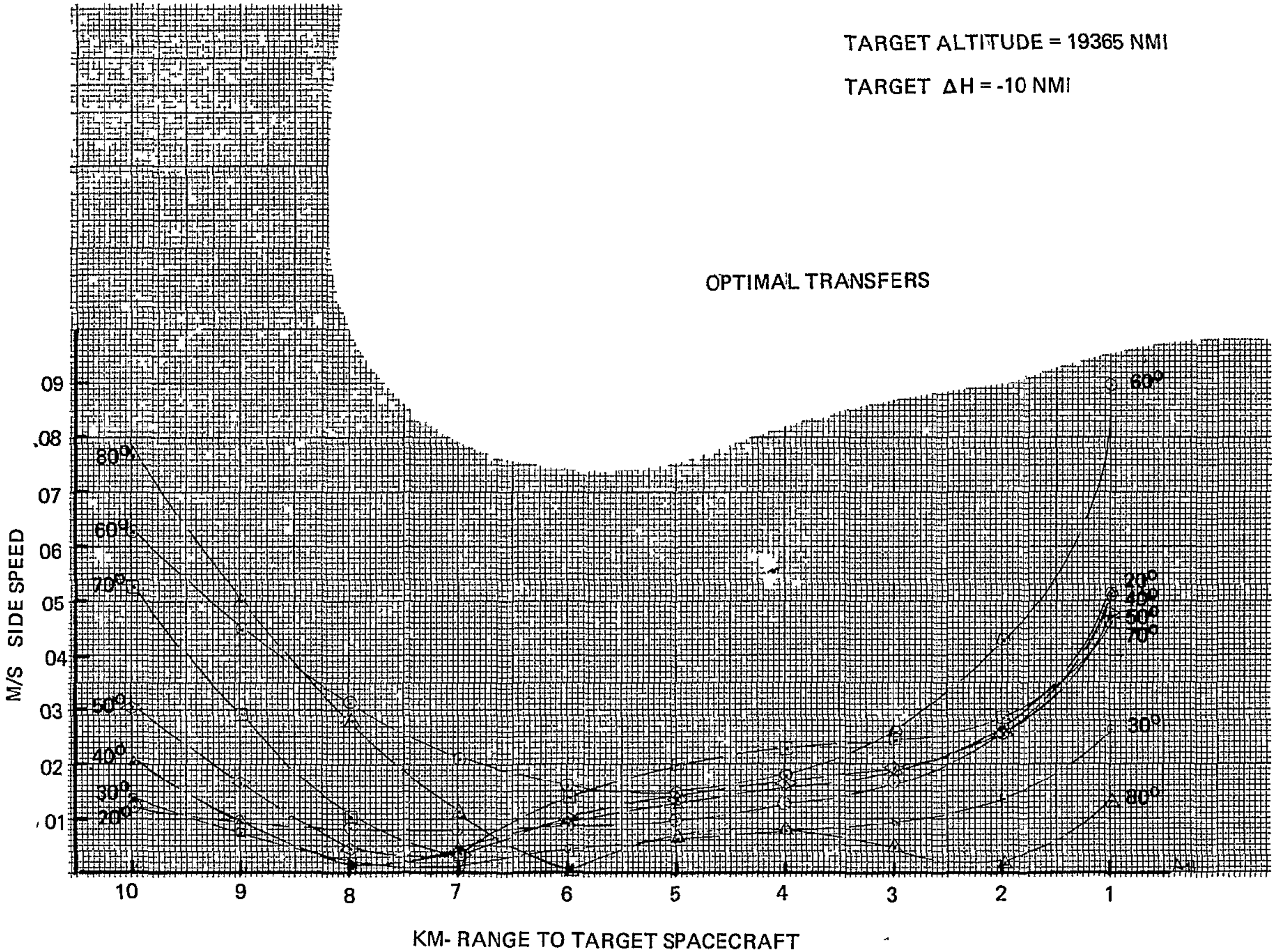

Figure 7 2 4-50 Parametric Relation Between Side Speed and Range for Various Transfers from -10 NMI ΔH at 19365 NMI Altitude

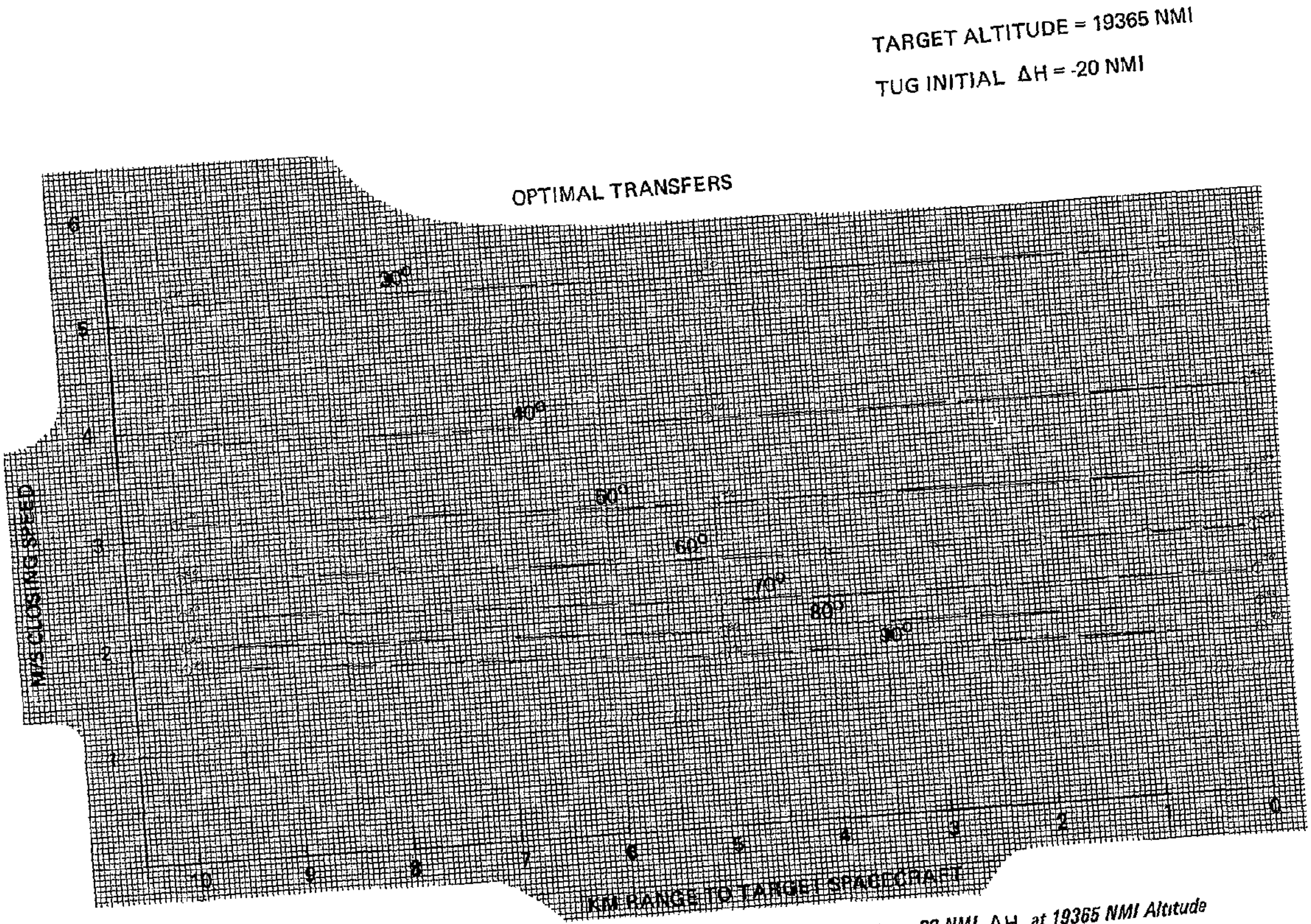

Figure 7 2 4-51 Parametric Relation Between Closing Speed and Range for Various Transfers from -20 NMI ΔH at 19365 NMI Altitude

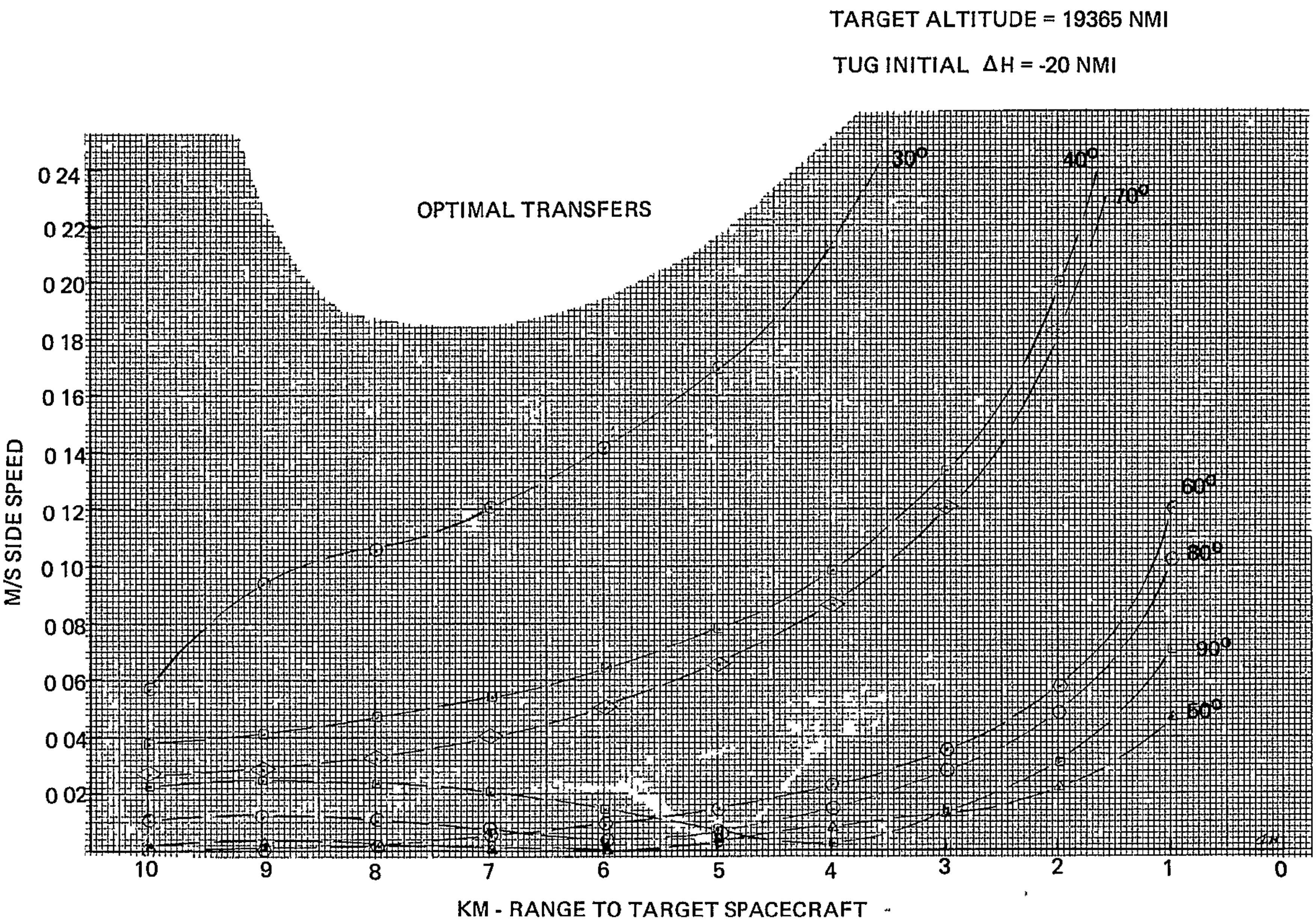

Figure 7 2 4-52. Parametric Relation Between Side Speed and Range for Various Transfers from -20 NMI ΔH at 19365 NMI Altitude

TARGET ALTITUDE = 19365 NMI

TUG INITIAL ΔH = -30 NMI

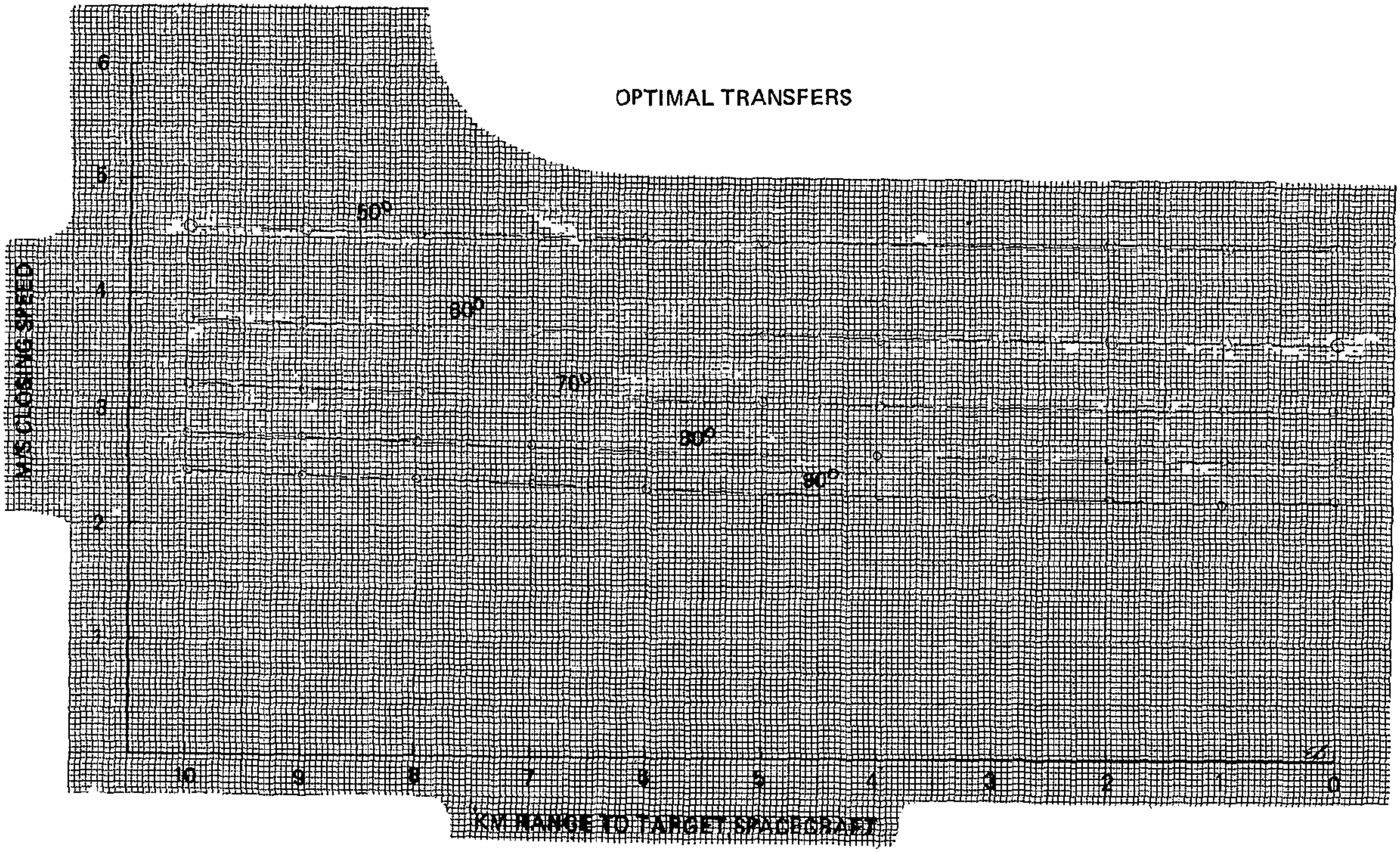

Figure 7 2 4-53 Parametric Relation Between Closing Speed and Range for Various Transfers from -30 NMI ΔH at 19365 NMI Altitude

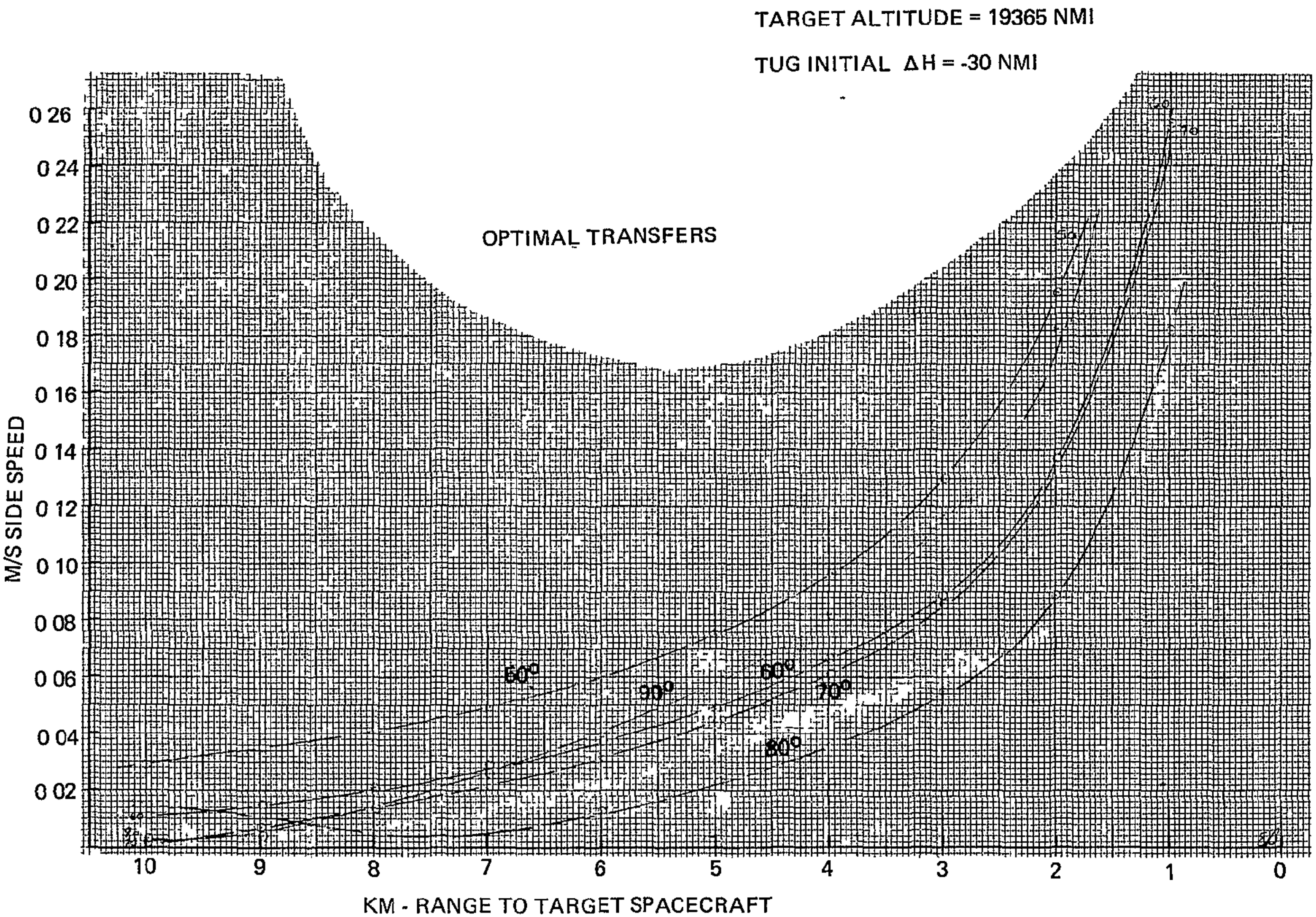

Figure 7 2 4-54 Parametric Relation Between Side Speed and Range for Various Transfers from -30 NMI ΔH at 19365 NMI Altitude

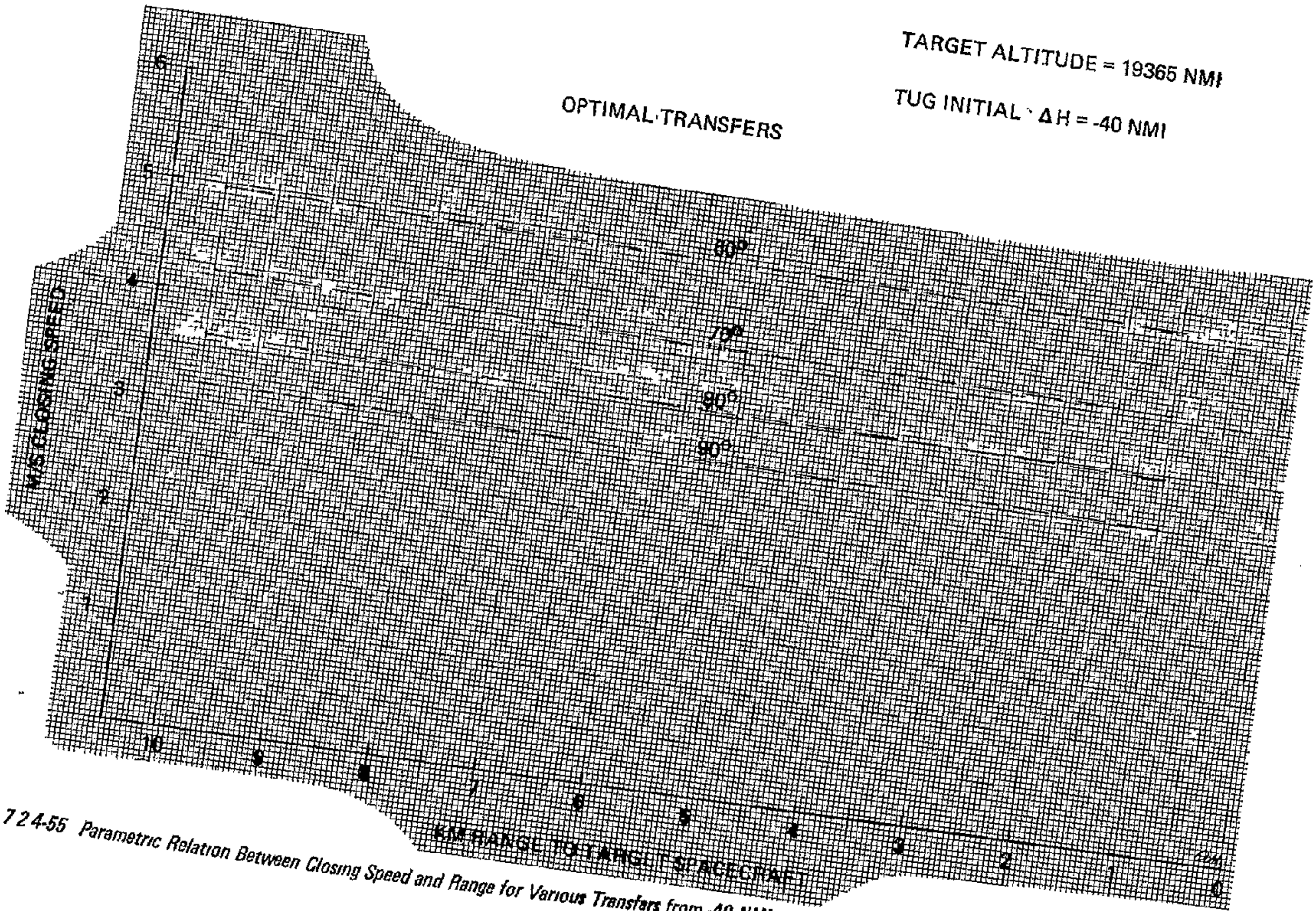

Figure 7.2.4-55 Parametric Relation Between Closing Speed and Range for Various Transfers from -40 NMI ΔH at 19365 NMI Altitude

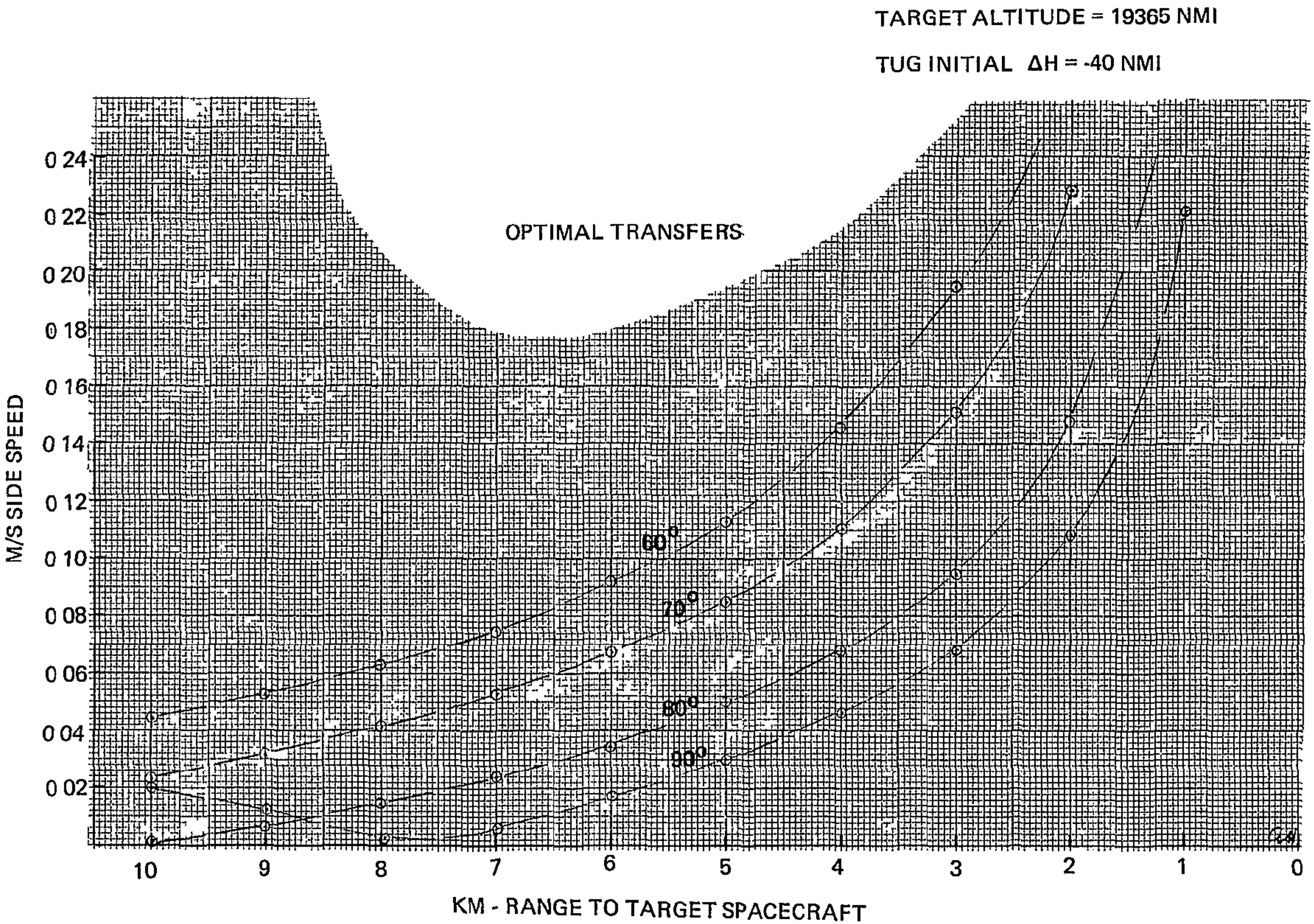

Figure 7 2 4-56 Parametric Relation Between Side Speed and Range for Various Transfers from -40 NMI ΔH at 19365 NMI Altitude

TARGET ALTITUDE = 19365 NMI

TUG INITIAL ΔH = -50 NMI

OPTIMAL TRANSFERS

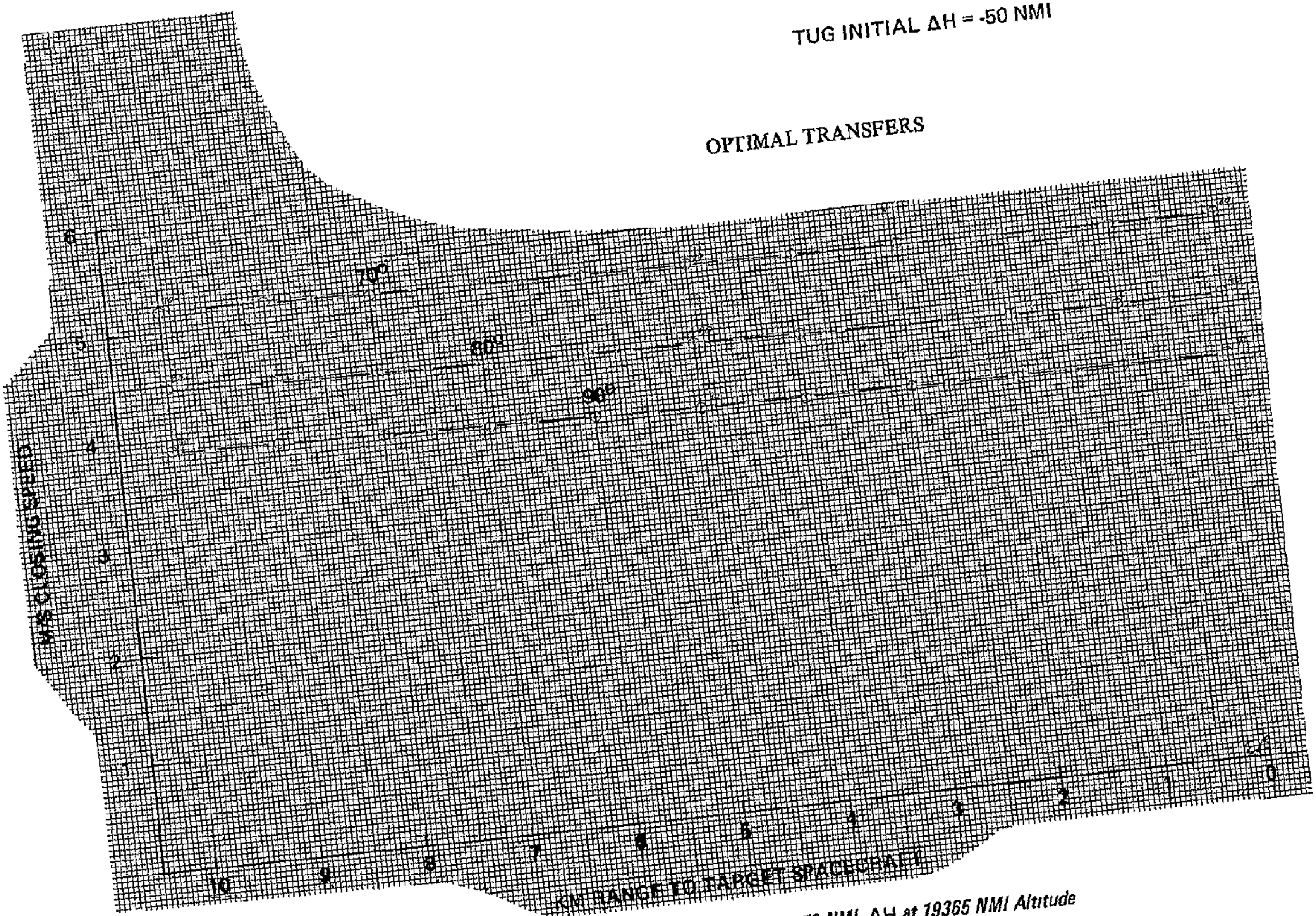

Figure 7 2 4-57 Parametric Relation Between Closing Speed and Range for Various Transfers from -50 NMI ΔH at 19365 NMI Altitude

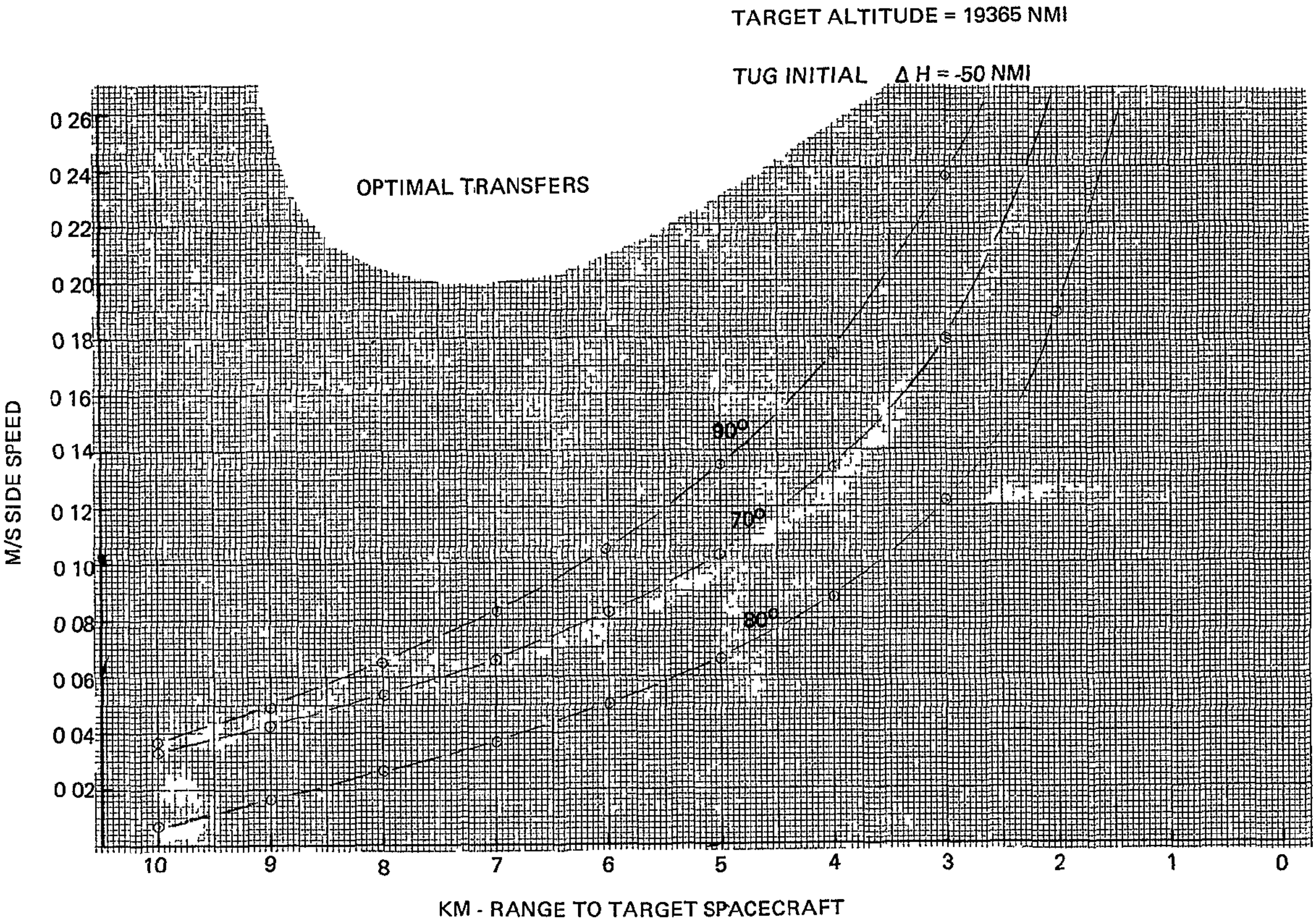

Figure 7 2 4-58 Parametric Relation Between Side Speed and Range for Various Transfers from -50 NMI ΔH at 19265 NMI Altitude

The cases at 19365 nmi , slight, but not significantly, above equatorial geosynchronous altitude, all yielded lower side-speeds than the other altitudes analyzed (Figure 7 2 4-50, -52, -54, -56 and -58) For initial height differentials of -10 nmi and -20 nmi , rolling minimal somewhat like those at 7000 nmi. were evident The transfers yielding the lowest side-speed appeared to be 80 degrees from -10 nmi , and 50 degrees from -20 nmi The curve natures were different for transfers from differential heights of -30 nmi , -40 nmi , and -50 nmi. The side-speed increased as range decreased The least side-speeds resulted from 80 degree transfers from -30 nmi and -50 nmi and 90 degrees from -40 nmi A representative lateral deadband magnitude is 0 07 m/s and this can be used to evaluate the side-speed magnitudes

7 2 5 Observations and Conclusions

The operational flow and the resultant parametric relations are intended to be data for use in understanding the constraints on rendezvous and docking, for developing rendezvous targetting philosophy, and for understanding the effect of rendezvous targetting on the docking variables

No docking parametric relations were developed because of the lack of a Tug simulator incorporating a slosh model

However, some preliminary assessment of rendezvous parametric relations is possible The baseline tracker acquisition range is possibly inadequate for pre-TPI acquisition Small navigation dispersions and TPI impulse budgets larger than the examples may ease the requirement for longer acquisition ranges but additional analysis is required

Analysis of non-optimal Lambert transfers should be undertaken as soon as possible because that class is possibly more likely than optimal transfers. The APS impulse budget for rendezvous and docking appears to drive the rendezvous tracker acquisition range requirement Additional and continuing refinement of the impulse budget, therefore, is required

The implementation of the final braking before Docking Inspection and Alignment commences may be implemented under phase-plane control, i e , a smoothe distributed impulse range-rate solution rather than a discrete burn As mentioned previously, the feasibility of this approach must be defined with more sophisticated techniques than were employed in this study

A detailed simulation of Tug body dynamics during docking to assess the effects of slosh on APS fuel usage and the effect of impact dynamics on Tug translational and rotational control is required to support analysis of the docking parameters

FLIGHT OPERATIONS SUPPORT ANALYSIS 8

During the IUS/Tug time frame, NASA's Spaceflight Tracking and Data Network (STDN) will consist of two subnets the Tracking and Data Relay Satellite System (TDRSS) subnet and the STDN ground site subnet The TDRSS will provide two Tracking and Data Relay Satellites (TDRS) plus a TDRSS ground terminal The post-1979 ground site subnet will be composed of six to eight sites from the STDN. Ground sites are currently planned at the following locations Goldstone, Madrid, Orroral, Fairbanks, Merritt Island (launch only), Rosman, Bermuda (launch only), and Tananarive (launch only)

The major functions of the STDN are to (1) track Spacecraft and relay launch and trajectory data in real-time from Spacecraft to control centers, (2) relay commands from control centers to Spacecraft, (3) relay telemetry and TV signals both in real-time and in store-and-forward modes from Spacecraft to control center, (4) relay voice communications between control centers and Spacecraft, and (5) augment recovery communications, as required

Although the present network provides sophisticated tracking and data acquisition support to earth-orbiting Spacecraft, it does have such limitations as Spacecraft access time, geographic coverage, and information bandwidth These limitations, in turn, impose design and operational constraints on the user Spacecraft To reduce these limitations, as well as to minimize the overall cost of tracking and data acquisition, NASA has been studying the use of a Tracking and Data Relay Satellite System (TDRSS) to augment the STDN

The TDRSS (see Figure 8 0.0-1) consists of two geosynchronous satellites, approximately 130 degrees apart in longitude, which will relay tracking, telemetry, and command data between low earth-orbiting user Spacecraft (<1200 Km), and a ground terminal located in the continental United States This concept also provides for two spare satellites, one in orbit, and the other in configuration for a rapid launch A "bent-pipe" concept is used in the design of the telecommunications service system (i e , all communication signals received at the Tracking and Data Relay Satellite (TDRS) are translated in frequency and retransmitted), making possible almost continuous reception of data in real time

8 1 STDN/TDRSS DATA FLOW

The data flow from the STDN and TDRSS is illustrated in Figure 8 1 0-1 Several paths are available to the user, dependent on which subnet of the STDN is being utilized If the user is transmitting data to either of the two TDRSS's, a direct flow is available to the White Sands ground station. The ground station will also function as a bent pipe repeater and process the data only to the extent that it is acceptable to the NASCOM interface NASCOM in this instance can provide land line capabilities up to 1 3 Mbps Domestic satellites are also being considered which will provide up to a 50 Mbps/transponder capability from the TDRSS ground station to the user

If the STDN subnet is used, several possibilities exist Data acquired by the sites located within the continental United States will be processed to interface with NASCOM Definition of the NASCOM capabilities for the Shuttle era has not been presented, however, a single land line capability will be

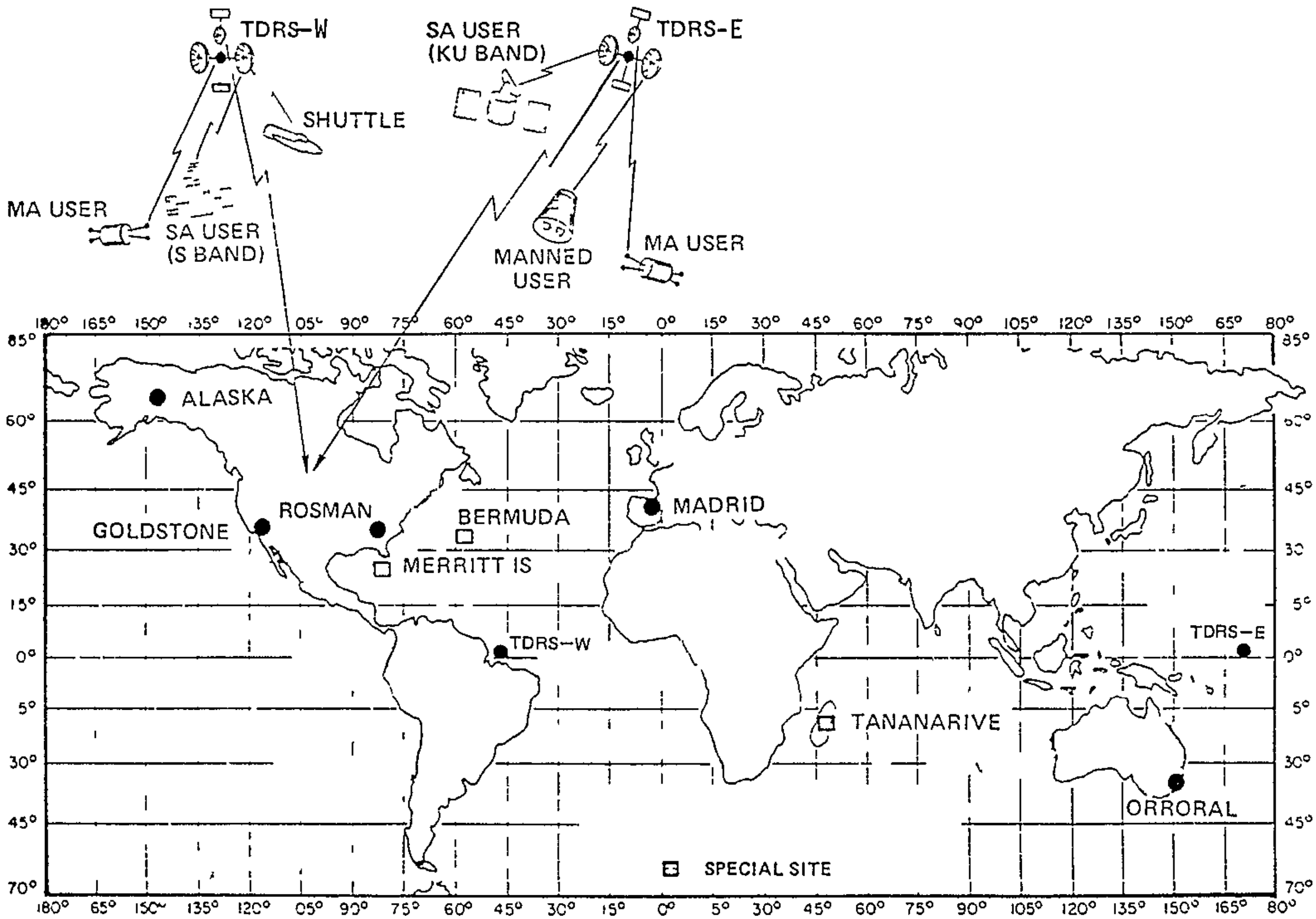

Figure 8.0-1 STDN and TDRS Subnets

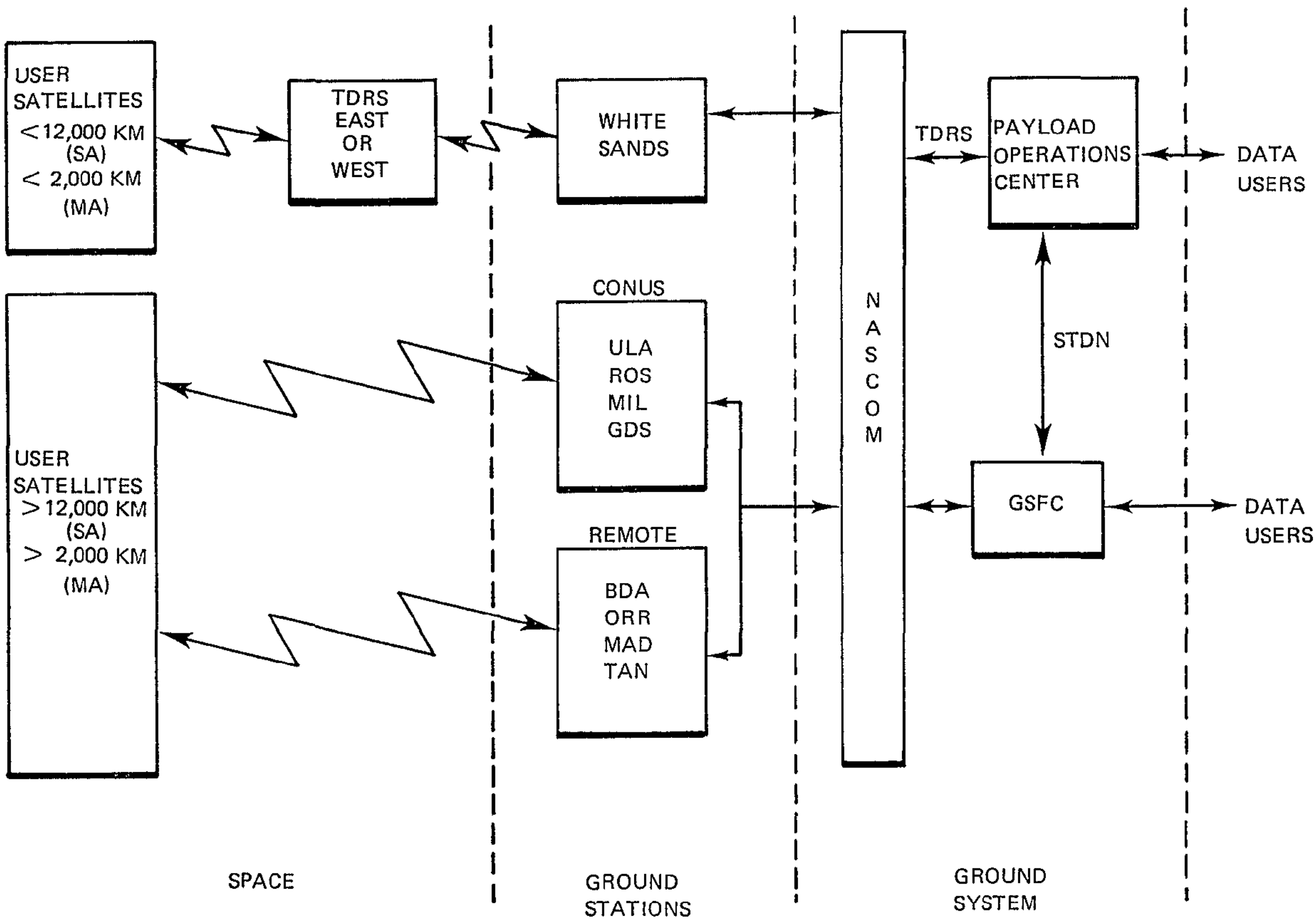

Figure 8 1 0-1 STDN/TDRS Data Flow

available for 1 3 Mbps NASCOM capability from the remote site is even more loosely defined Presently, a 21 2 Kbps capability exists at the STDN stations The Deep Space Network (DSN) and Fairbanks (ULA) have a wideband circuit to GSFC capable of 28 5 Kbps Rosman has a 1 5 MHz circuit to GSFC This may be increased by the use of satellite communications or other NASCOM enhancements It is expected that data from the STDN will be routed to GSFC, GSFC in turn will act as a switching and distribution center to re-route the data to the users

8 1.1 <u>STDN/TDRSS Telemetry Data FLow and Processing</u>

It is planned that both subnets will present the same interface to the STDN user and both can provide telemetry, command, and tracking to any user The capabilities planned at the STDN subnet interface have not been defined at this time

8 1 1 1 TDRS Telecommunications Links

The concept of the TDRS telecommunications links is explained below as a basis for TM data flow and processing (reference Figure 8 1 1-1)

The telecommunications link from the ground terminal to the TDRS to user is called the forward link, and the link from the user to TDRS to the ground is called the return link The forward links carry user command data, tracking signals, and voice transmissions, and the return links carry user telemetry data, return tracking signals, and voice Both the forward and return links consist of two segments

- <u>Space-to-Space Link</u> - This is defined as the link between the TDRS and the user Spacecraft

- <u>Space-to-Ground Link</u> - This is defined as the link between the TDRS and the TDRSS ground terminal

Each TDRS contains the following antennas to support the space-to-space communication links and the space-to-ground communication links

- <u>Space-to-Space Communication Links</u> -

  (1) One 40-element, S-band antenna system 10 elements are used to support the forward link, the remaining 30 elements are used as an array antenna to support the return (telemetry) link of 20 users simultaneously This antenna system is called the Multiple-access (MA) system, user Spacecraft supported on this system are called MA users

  (2) Two 3 8-meter parabolic antennas operating at S- and Ku-bands Each antenna system is called a Single-access (SA) system because each antenna normally will support one user at a time However, each antenna can support two users simultaneously (one at S-band and one at Ku-band) provided both users are within the beamwidth of the antenna The user Spacecraft supported on these antennas are called S-band Single-access (SSA) users or Ku-band Single-access (KSA) users

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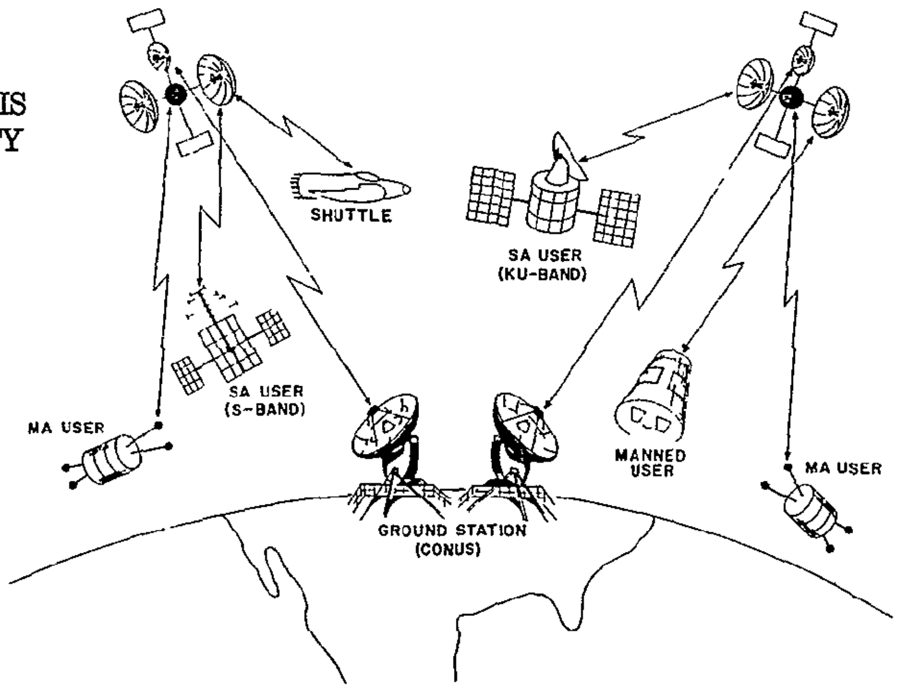

Figure 8 1.1-1. Two Satellite TDRSS Concept

- Space-to-Ground Communication Links - One 1 8 meter, parabolic Ku-band antenna

8 1.1 2 TDRS Users

The users of the TDRSS are classified by the type of service they require from the system.

- Multiple Access User - The MA user is an S-band user serviced by the TDRS phased array. The maximum return link bit rate under most circumstances is 100 Kbps

- S-Band Single Access User - The SSA user is serviced by one of the 3 8 meter parabolic antennas on the TDRS The return link bit rates can vary from 1 Kbps to 6 Mbps

- Ku-Band Single Access User - The KSA user is serviced by one of the 3 8 meter parabolic antennas on the TDRS. The maximum bandwidth is 225 MHz, thereby providing a 150 Mbps biphase or a 300 Mbps quadriphase bit rate on the return link

8 1 1 3 TDRS Telemetry Flow

Two of the three user services provided by the TDRS, MA, and SSA are explained in further detail in the following paragraphs. The Single Access Ku-band system capability far exceeds Tug requirements at this time

Each TDRS will be designed to support a minimum of 20 MA users simultaneously The multiple access system employs a 30-element S-band phased array antenna to minimize onboard complexity Adaptive beam forming functions are performed at the ground station The MA link performance for each user is a function of the number of MA users within view of the TDRS, their data rates, and power outputs

Each user may have a different data rate The average user's raw real-time data rate is 11 5 Kbps plus overhead (approximately 10 percent) or approximately 12 7 Kbps To this, each user spacecraft may add 15 percent for the transmission of data stored onboard during the blind period, thereby yielding an average rate of 14 6 Kbps The total data rate for 20 users plus overhead is, therefore, approximately 292 Kbps From time to time, users in the system will change as new Spacecraft are launched and old ones are discontinued Data rates may increase up to 25 percent on the average for the projected system The total bit rate from the S-band array may, therefore, be projected as high as 365 Kbps through the ground links

The TDRS SSA return link includes two 3 8 meter antennas steerable by ground command Autotrack capability does not exist due to weight considerations The SSA service provides a 10 MHz receive bandwidth and throughput capability of 1 Kbps to 6 Mbps The 10 MHz bandwidth is sufficient to accommodate video, however, no provisions are made at this time to accommodate video data at the TDRS ground station

SSA and MA return link data is frequency translated onboard the TDRS for transmission to the ground in the Ku-band frequency range

8 1 1 4 TDRS Ground Terminal

The TDRS ground terminal provides three primary services (1) forward user commands to the TDRS for transmission to user spacecraft, (2) receive user TM and provide the NASCOM interface for transmission to the user, and (3) receive Range and Range Rate data as an input to the GSFC orbit determinitation system

The ground terminal will be capable of receiving and handling downlink data from 20 MA users, 6 KSA users, and 6 SSA users simultaneously. However, for the SA systems only 4 KSA and 4 SSA data streams from the two operational Spacecraft will normally be scheduled The ground terminal will

a Receive the return links from the two operational TDRSs The receiving system is designed to provide a sufficient signal margin for reliable contact between the satellites and the ground terminal.

b Demultiplex the received signals to recover user Spacecraft data and ranging data

c. Generate the proper PN codes for extracting range information, and, in the case of the MA users, uniquely identifying each of 20 user Spacecraft

d Demodulate the received user Spacecraft telemetry in accordance with the modulation technique used

e. Bit synchronize, and decode the user telemetry in such a manner to interface with NASCOM for transmission to the appropriate user control center and/or the data processing system at GSFC, or other non-GSFC locations

The content of user Spacecraft telemetry will not be monitored or altered at the ground terminal. It will be routed via NASCOM to the appropriate user control and data processing facility. Presently, all data will be routed to the user as it is acquired by the TDRS ground station in a real time mode On-site storage capability for store and forward is not being planned Because users of the TDRSS are divided into primary categories, MA and SA users, the methods of ground data handling will be somewhat different

The MA user channels are recovered by demultiplexing the converted Ku-band return link from the TDRS A signal to interference ratio can be established for each MA user by combining signals received from the various elements of the MA antenna array in the proper magnitude and phase The SSA channels are also recovered from the converted Ku-band signal Beam forming is not necessary for SSA user signals.

8 1 2 STDN/TDRSS Tracking Modes and Processing

The TDRSS ground terminal is assigned to be furnished with a single tracking data processing system providing both high and low rate sample range and range rate (R&RR) data for all Spacecraft tracked via TDRSS in a standard format. The estimated maximum data rate, including transmission overhead, is 4 8 Kbps This channel will be active almost continuously and at present is considered to be routed through to the GSFC orbit computation center, but also may be bridged to other locations.

The user MA system must be capable of providing PN code coherence so that ranging computations can be performed on the ground Because PN code modulation is used in both forward and return links, a PN code synchronization must be established before any functions can be performed. After synchronization, data can be transmitted in both directions Ranging is accomplished by computing the transit time of the signal from TDRS to user to TDRS

The ranging subsystem accepts digital R&RR data from the RF system MA and SA demodulators and processes it for delivery to the Orbit Determination System (ODS) via the NASCOM interface It also accepts TDRS R&RR data from the RF system bilateration correlator, or alternatively, from the S-band backup system TDRS demodulator The ranging subsystem uses this data in two ways First, it processes the data for delivery to ODS via the NASCOM interface Also, it performs some on-site calculations to provide ranging information to the attitude and stationkeeping processor

TDRSS tracking capability can be summarized in the following manner User satellite position in near polar orbits can be determined to an uncertainty of 60 meters and accuracy is degraded as the user inclination approaches that

of the TDRS Tracking accuracy is dependent on the length of the data arcs and the number of supporting TDRSs (1 or 2).

The TDRSS is expected to provide three types of user services The first two services are defined for information; the third for its applicability to Tug

- <u>Routine Orbit Determination</u> - Necessary only to establish orbits sufficient to predict future satellite position for acquisition by ground station and TDRSS and for network scheduling data

- <u>Precision Orbit Determination Accuracy</u> - Necessary for satellite systems to properly analyze and evaluate sensor data Requirements today exist for 100 meters or less Future requirements may be more stringent

- <u>Real Time Orbit Determination</u> - Accuracy necessary for those satellite subsystems which must execute maneuvers and guarantee Spacecraft and/or Shuttle crew safety Accuracy requirements will vary dependent on mission, however, short data arcs taken in a limited amount of time will be the rule of the day

8 1 3 <u>STDN/TDRSS Command Flow and Processing</u>

The TDRSS forward link (command) is characteristically described by the type of user - single access or multiple access

The MA command channel of the TDRS radiates via the 10 element transmit array The MA uplink is a single frequency time division system with the capability to command only one MA user at a time The user will interface with the TDRS ground terminal The ground terminal will provide the proper scheduling and support element selection (antennas, transmitters, carrier modulation, etc ,) to the user To be consistent with the throughput philosophy of the TDRSS user, commands will be generated, transmitted, executed, and verified by the applicable user control center The forward link will support MA user requirements up to 10 Kbps Uplink commands from the user control center will be in a real time mode only, command storage and load capability does not exist at the ground station

The SSA forward link user can operate in a narrowband or wideband (under consideration) mode Uplink data rates are variable from 100 bps to 500 Kbps Operational considerations for the SSA forward link are similar to the MA characteristics of the last paragraphs

8 2 NETWORK CHARACTERISTICS AND CONFIGURATION

The eight station STDN subnet and single TDRS ground station comprise the STDN. As part of the STDN, operational control of the TDRSS ground terminal will be exercised by the Network Operations Control Center (NOCC) The NOCC will send the ground terminal a weekly user support schedule via NASCOM The schedule will specify the support times, user Spacecraft frequencies, and Acquisition of Signal/Loss of Signal (AOS/LOS) times. This basic support schedule will be used to generate a detailed TDRSS utilization schedule, i.e , an activity plan Other inputs to the activity plan will include (a) user and TDRS data, (b)

ground terminal status, and (c) other required TDRS commands. The same types of utilization schedules are expected to be provided to the eight STDN stations.

The STDN is configured to provide two types of support (1) launch support and, (2) high altitude satellite support The launch support stations will be configured and scheduled for that express purpose Even though the support configuration has not been finalized, it is expected that the launch stations will not have the full capability of the other STDN stations Fairbanks will provide support to the high inclination orbits, while Orroral, Madrid and Goldstone will be significant to those missions requiring support characteristics of the Deep Space Network (DSN)

The STDN and TDRSS significantly differ in their design and support concepts. It follows then that their operational constraints are different.

8.2 1 STDN Network Operational Constraints

The STDN will function primarily as a high altitude mission support network, and operational support constraints will be described as they relate to these objectives.

Keyhole Considerations - The STDN will probably utilize one or more of the three basic S-band antenna systems, the 9 meter (30'), 12 meter (40'), or 26 meter (85') parabolic dish These antenna systems utilize an X-Y mount. The X-Y mount application is used because zenith coverage is accomplished which is not possible with the convential Az-EL mount The X-Y mount is capable of tracking through zenith but has a gimbal restriction keyhole near the horizon. The restriction is generally oriented north to south on the 9 meter systems and east to west on the 26 meter systems (Figure 8.2.1-1). Signal loss is most significant during low altitude missions and becomes less significant as altitude increases In the past, losses up to a 15 degree antenna elevation angle has occurred. Additional time may be required during a pass to re-acquire phase lock once the vehicle has passed through the keyhole

Terrain Features - In addition to the keyhole effect, S-band antenna system performance will be degraded by terrain features, i e., mountainous terrain Obviously, this is related to station location.

Attitude Considerations - The onboard S-band phased array antenna will have a limited beamwidth To maintain satisfactory communications with the ground stations at acceptable gains and bit error rates, the attitude and pointing of the vehicle will be restricted.

Handover Considerations - At altitudes above 6500 KM, the STDN should be able to provide continuous coverage of the vehicle. During this time period signal losses during handover should be minimal, since downlink lock can be established by more than one station. Handover becomes primarily procedural. If handover is complicated by vehicle attitude constraints, ground terrain features, or the keyhole effect, then the signal loss may be more significant.

STDN Ground Station Configuration - The STDN will be configured to primarily provide support to high altitude missions Three stations, MILA, BDA, and TAN are configured for launch support only, and manning levels for these

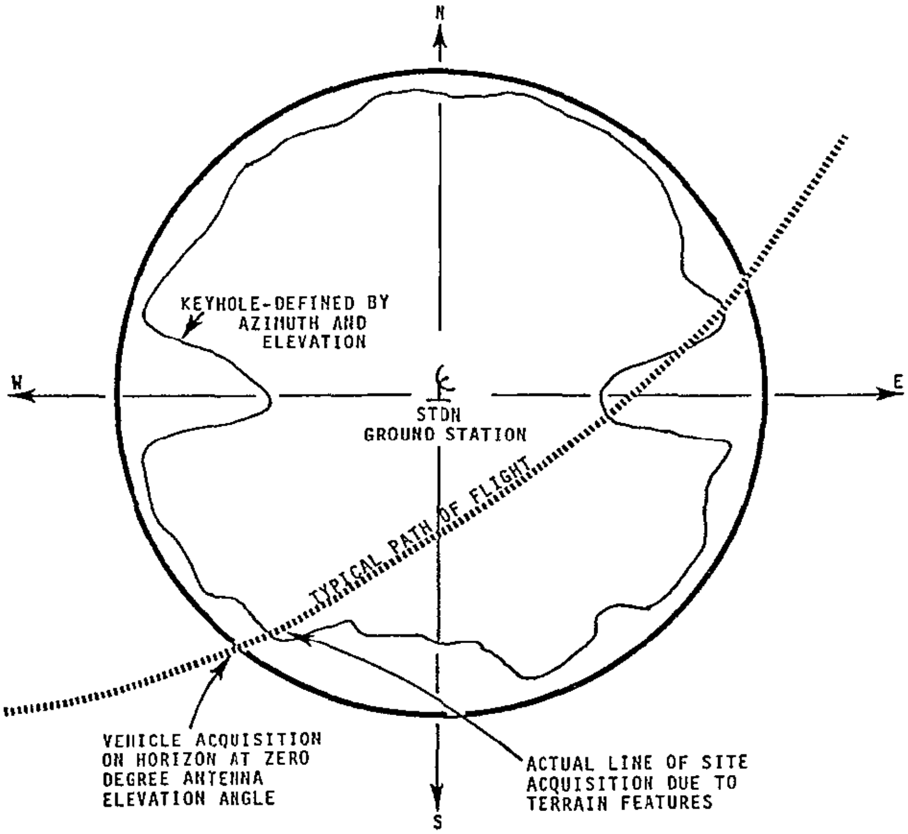

Figure 8 2 1-1 S-Band Antenna Keyholes

stations will be based on a single shift operation Four to five stations remain for orbital support Fairbanks (ULA) will not provide meaningful low earth orbit, low inclination support Hence, the STDN is reduced primarily to a four station network which is not capable of or designed for significant low altitude support

8 2.2 TDRSS Network Operational Constaints

The TDRSS will function as the low altitude mission support subnet, and its primary operational constraints are as follows

Handover Considerations - Assuming the vehicle has only one S-band antenna, three types of handovers must be considered (1) vehicle to TDRS-E or TDRS-W, (2) TDRSS ground antenna switching, and (3) possible handover to and from the STDN.

Positional location of the vehicle S-band antenna will be signficant because of (1) the need to slew the onboard antenna from one TDRS to another, and the associated antenna slew times, and (2) the possible need for vehicle attitude changes to ensure communications

Of less significance will be the switching of the data source from one TDRS ground antenna to another as an input to the ground station data handling system

Handovers from one subnet to another subnet may result in signal losses, again dependent on the geometry involved relative to the vehicle, TDRS and STDN. The following paragraphs will further explain the possible problems

<u>TDRS Earth Occultation</u> - The TDRS consists of two active geosynchronous satellites 130 degrees apart in longitude on station over the equator. The two active satellites do not provide full orbital coverage of the user vehicle due to earth occultation Communications interruptions occur in what is termed the "zone of exclusion", with its cause and location illustrated in Figure 8 2.2-1 The zone of exclusion represents the lower altitude coverage limits for the TDRSS users, which is less than 1200 kilometers. The amount of coverage provided to a user spacecraft is a function of the user' altitudes and inclinations. User at low altitudes and inclinations will pass through the zone of exclusion on each orbit and receive the least coverage However, users at higher altitudes and inclinations will pass through the zone of exclusion only periodically, e g., a user at 1000 kilometers altitude and 99 degrees inclination will pass through the zone of exclusion once per day or less

<u>Tug Antenna Occultation Considerations</u> - Vehicle antenna masking could be caused by the vehicle structure occulting the S-band antenna and the TDRS. This situation may occur if the space vehicle is held in an attitude with at least two axis fixed over an extended period of time

<u>User Coverage Constraints</u> - The user can be provided with 100 percent coverage at altitudes greater than 1200 KM. Twelve hundred kilometers represent the lower coverage limits of the TDRSS The upper coverage limits for the single and multiple access systems are 12,000 KM and 2000 KM, respectively. A summary of the TDRSS orbital coverage follows

- <u>Multiple-access</u>

  (1) Minimum coverage at 200 kilometers
  (2) 100 percent coverage between 1200 and 200 kilometers
  (3) Coverage decreases towards zero for synchronous altitudes.

- <u>Single-access</u>

  (1) Minimum coverage at 200 kilometers.
  (2) 100 percent coverage between 1200 and 12,000 kilometers
  (3) Coverage decreases towards zero at synchronous altitudes

8 3 SPACE TUG MISSION COMMUNICATIONS ANALYSIS

Three representative Tug missions were baselined for a network support study. Orbital trajectories were calculated for interplanetary, sun synchronous, and geosynchronous missions, and line of sight geometric support by the STDN and TDRSS was assessed. In the initial assessment, all STDN sites were included, to provide a confidence that useful stations were not prematurely discarded. Table 8.3.0-1 illustrates possible mission support by percentage of mission time.

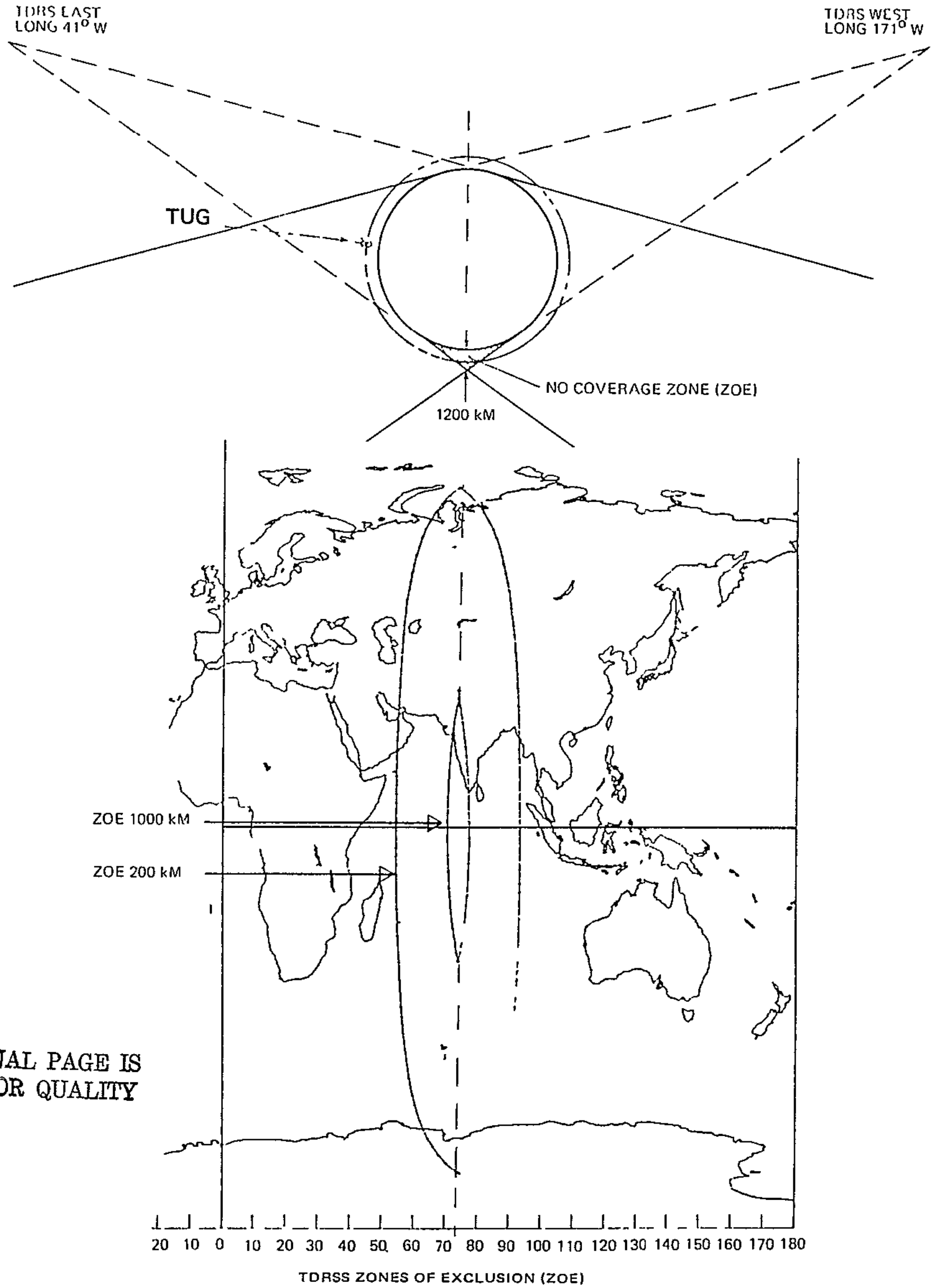

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Figure 8 2 2-1 TDRS Zones of Exclusion

Table 8.3 0-1. STDN/TDRSS Station Coverage

NASA MISSION		INTERPLANETARY	SUN SYNCHRONOUS	GEOSYNCHRONOUS DELIVERY
MISSION LENGTH (DAYS)		1 27	0 62	2 39
STATION ACQUISITION PERCENTAGE OF TOTAL MISSION TIME	MIL *	8 4	6 6	40 8
	ROS *	4 9	7 8	40 8
	BDA	4 0	6 5	40 8
	MAD *	0 7	1 9	40 8
	CYI	2 6	0	40 8
	ACN	1 4	0	41 1
	TAN	18 3	6 8	8 4
	ORR *	64 9	3 1	17 4
	GWM	52 0	1 3	17 4
	HAW	46 9	2 5	7 1
	ULA *	0	5 7	0
	GDS *	23 8	5 3	40 8
	QUI	19 9	5 9	40 8
	AGO	22 9	4 8	41 1
	TDRS-E	49 7	84 6	15 0
	TDRS-W	44 9	67 4	12 5

*Planned ground stations

Generalized ground support requirements for each phase of the Tug missions are

Phase / Req'mt	Orbital Checkout Deployment, Coast, Midcourse Corrections	Burn Phases	Payload Delivery, Rendz. & Docking, Visual C O
Telemetry	16 Kbps	64 Kbps 256 Kbps (Received)	16 Kbps 64 Kbps TV
Command	2 Kbps	2 Kbps	2 Kbps
Tracking	No Requirement	No Requirement	No Requirement

8 3 1 Sun Synchronous Mission Coverage

The sun synchronous mission was analyzed for 0 62 days in length The ascent burn delivered the vehicle to an altitude of 920 nautical miles where a circularization burn placed the vehicle into a circular orbit The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Orroral and Madrid

Figure 8 3 1-1 is a timeline of mission events and composite AOS/LOS of the TDRS's and STDN stations AOS/LOS and mission events are also shown in perspective on the mission trajectory traces in Figure 8.3 1-2 and 8.3 1-3 Only pertinent orbits are shown to maintain simplicity and ease of understanding The following conclusions are based on the known support periods, support station capabilities, and onboard system output rates

- The STDN does not provide any coverage during three critical mission time periods, ascent burn, circularization burn, and the retro burn.
- The TDRS can provide support for all burn periods.
- The STDN will augment the TDRS only during one time period, after retro burn and before circularization burn Because of the high vehicle altitude, Orroral can provide limited coverage
- The TDRS provides the necessary low altitude support for which it was designed, adequately. The STDN is not required for low-earth orbit support.
- If the Tug outputs data at 64 Kbps or higher (possibility 256 Kbps) during burn periods and the recorder dump periods, the MA system will not sufficiently support the Tug and other users. This will necessitate the need to schedule SSA user service capability Tug systems must have the capability to interface with both the MA and SSA or the SSA only. TDRS user interface documentation indicates that an MA user can be supported by the SSA system. Data rates would be restricted to a maximum of 300 Kbps in this case

8 3.2 Geosynchronous Delivery Mission

The geosynchronous delivery mission was analyzed for a mission time of 2 39 days The ascent burn delivered the vehicle to an altitude of 19,323 nautical miles where a circularization burn placed the vehicle in a stationary geosynchronous position at -71 degrees longitude The retro burn returned the Tug to an altitude of 170 nautical miles where a circularization burn placed the vehicle into a circular orbit. The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Madrid, and Orroral. As with the sun synchronous mission, MIL, ROS, and ULA provided minimum additional coverage

Figure 8 3 2-1 is a timeline of the geosynchronous delivery mission and summarizes the orbital support of both subnets depicted in Figures 8.3 2-2 and 8.3 2-3 The following conclusions can be drawn from the timelines and the known network capabilities discussed previously in this section

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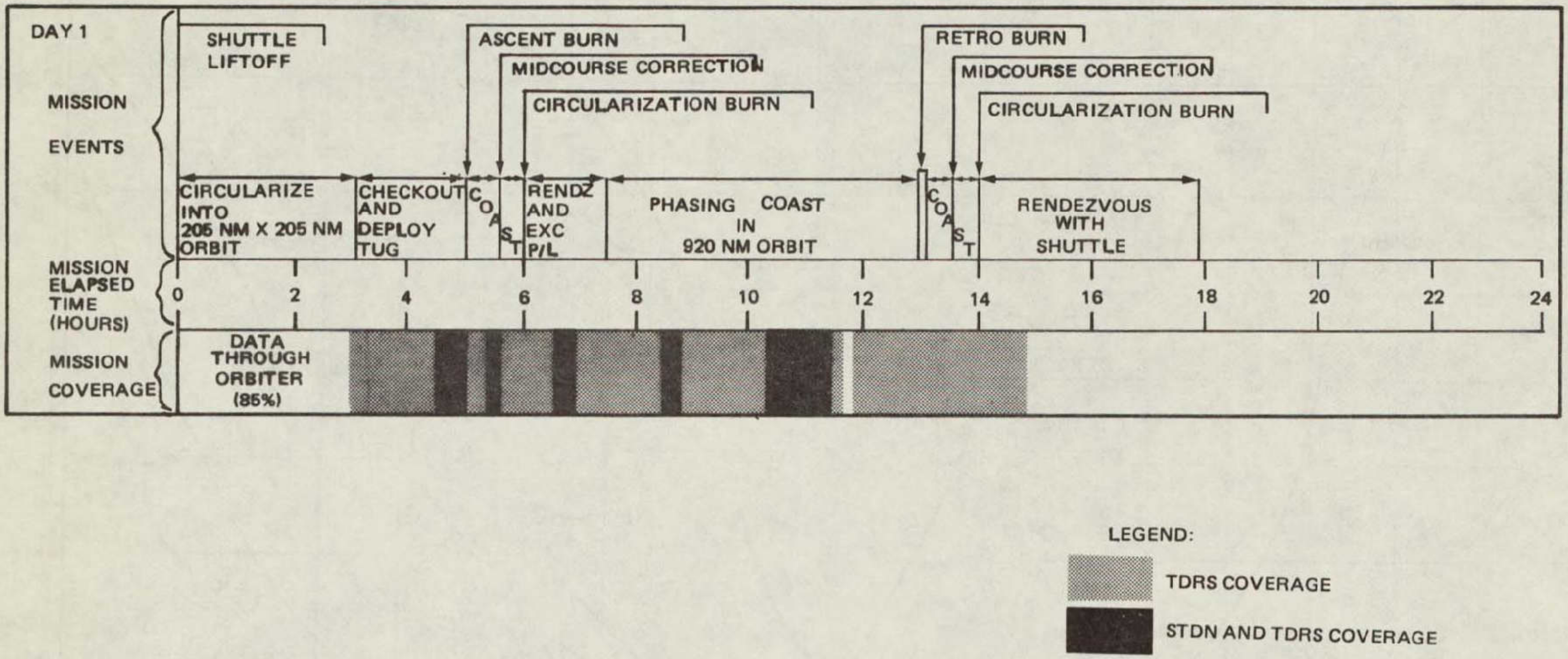

Figure 8.3.1-1. Tug Sun Synchronous Mission Timeline (3 Station STDN and TDRS)

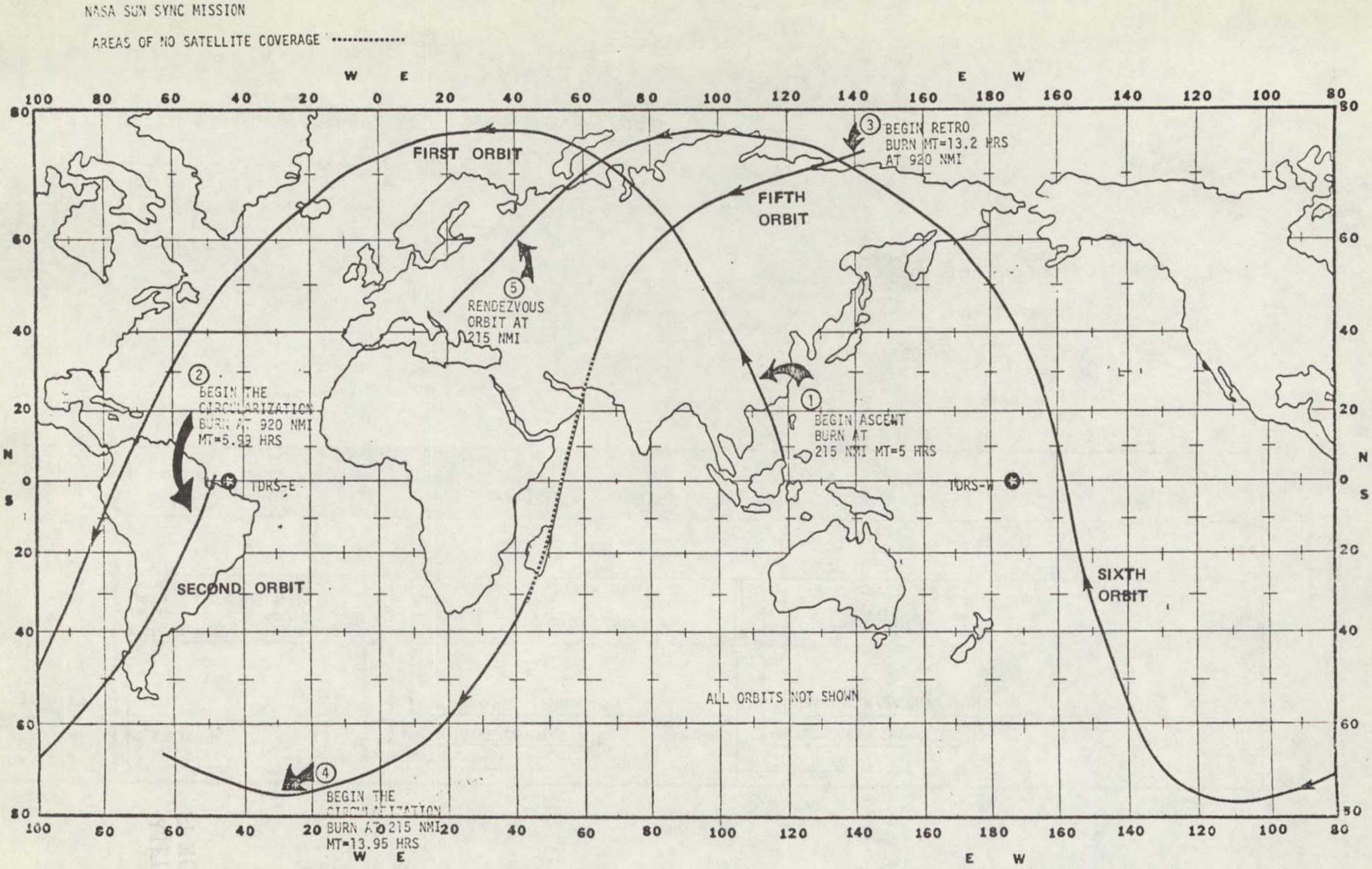

Figure 8.3.1-2. Tug Sun Synchronous - TDRS Only Case

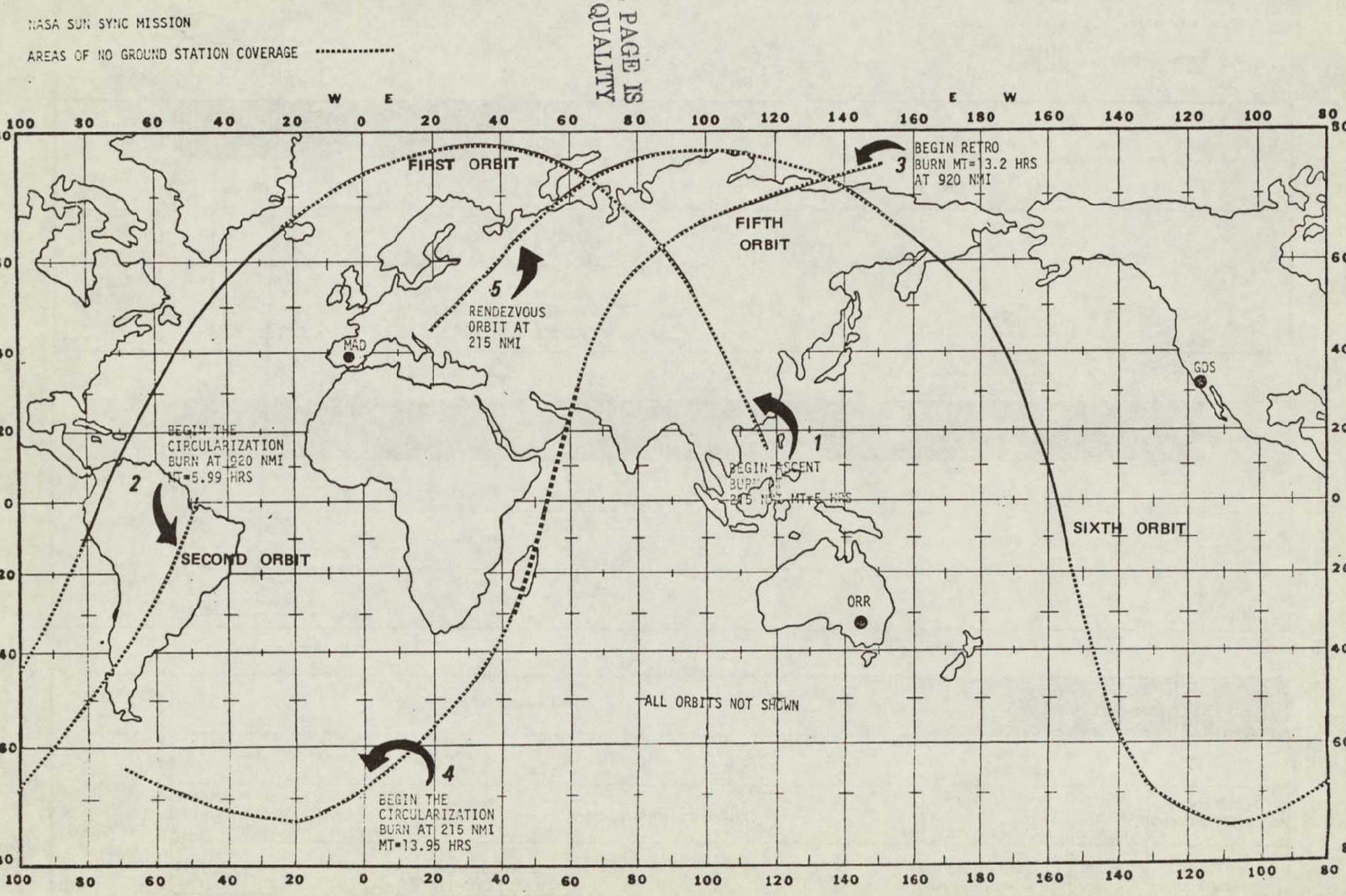

Figure 8.3.1-3. Tug Sun Synchronous - STDN Only Case

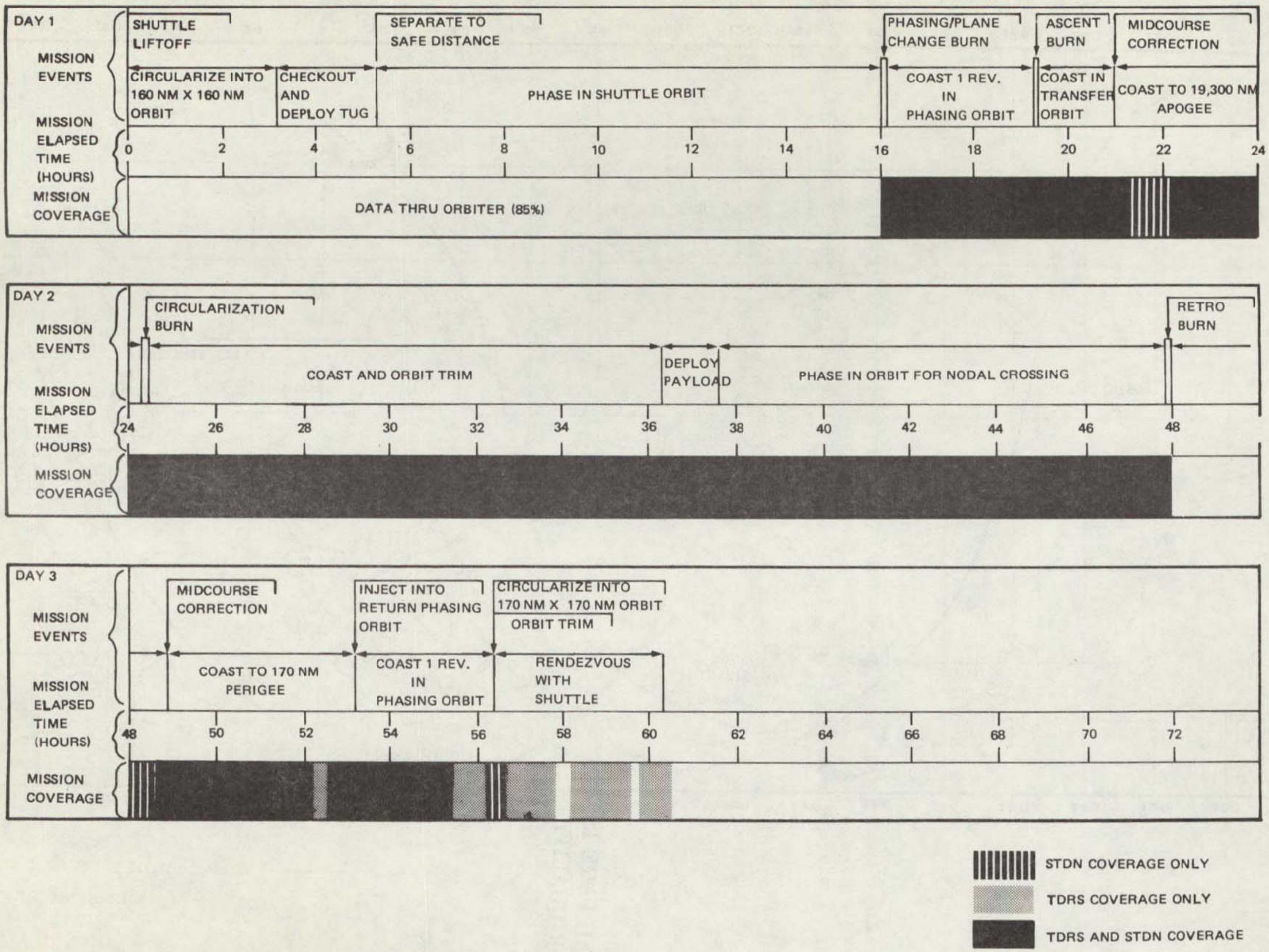

Figure 8.3.2-1. Tug Geosynchronous Delivery Mission Timeline (TDRS/STDN)

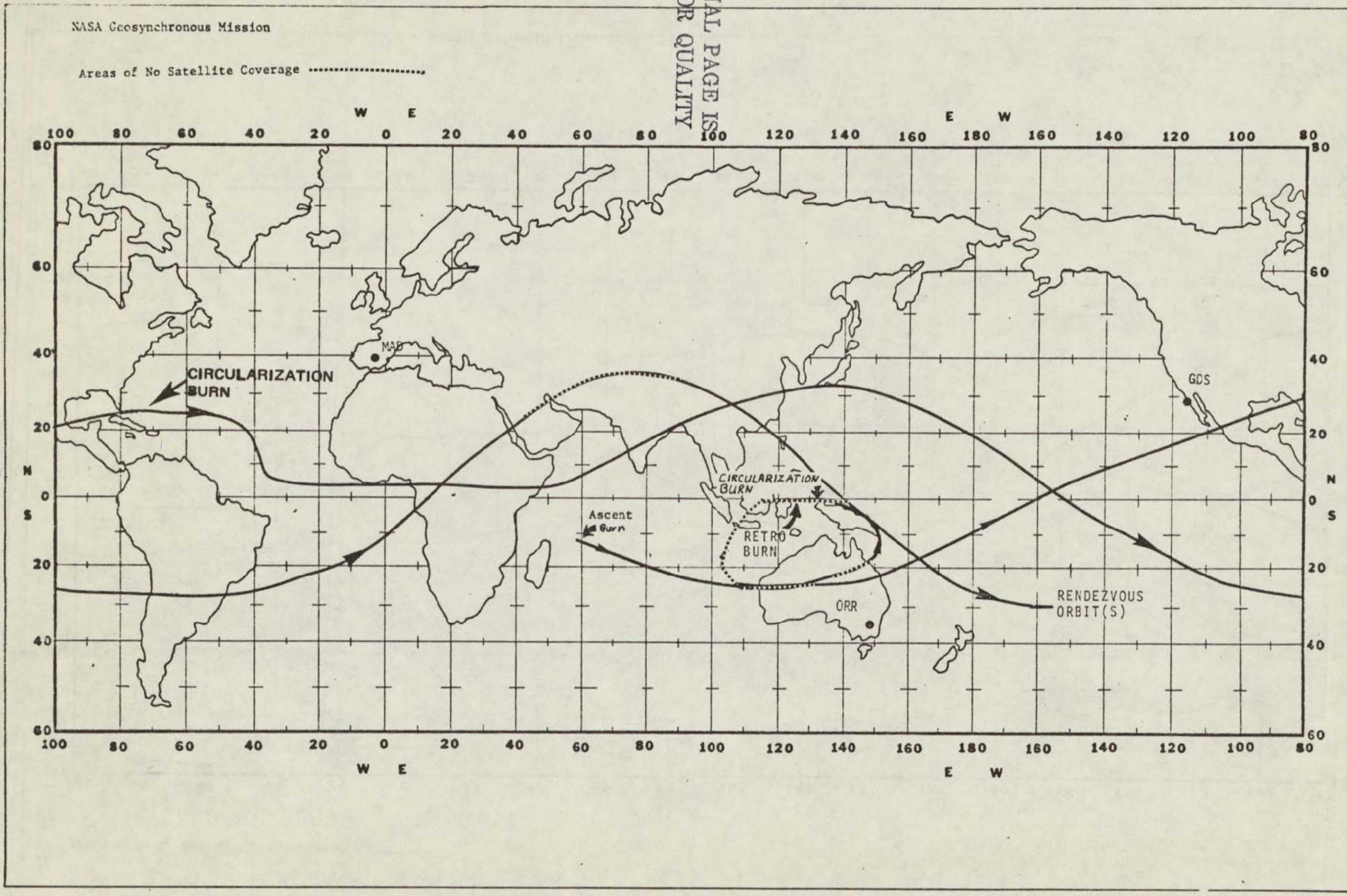

Figure 8.3.2-2. Tug Geosynchronous - TDRS Only Case

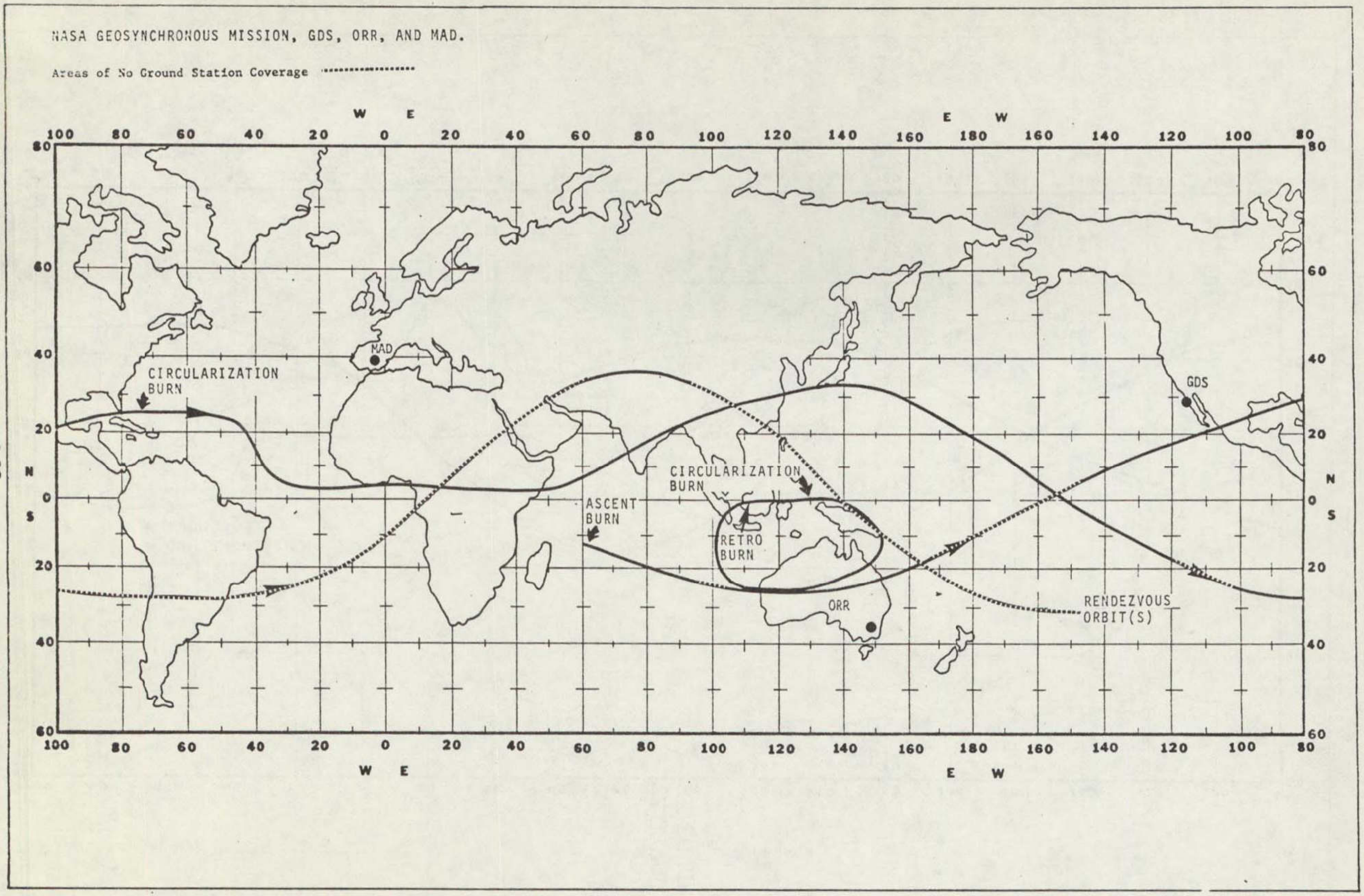

Figure 8.3.2-3. Tug Geosynchronous - STDN Only Case

- The STDN subnet can provide support to all major burn periods; however, during low altitude rendezvous with the Orbiter, support is limited.

- Because of the altitudes involved, the TDRS cannot support the retro burn for return. The TDRS can support the rendezvous phase with the Orbiter.

- The geosynchronous mission will require the coordinated support of the STDN and TDRS subnets.

- If the Tug outputs data at a 64 Kbps rate or 256 Kbps rate during burn periods, the MA system will not sufficiently support the Tug and other users. This may necessitate the need for the SSA user service capability. Tug systems may have to have the capability to interface with both the MA and the SSA user systems.

8.3.3 Interplanetary Mission

The interplanetary mission analyzed was 1.27 days in length. The ascent burn delivers the kick stage/payload to an altitude of 737 nautical miles at 22 degrees latitude and 155 degrees longitude where separation occurs. The ascent burn sent the Tug into a high elliptical orbit with an apogee of approximately 30,000 nautical miles. The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Orroral, and Madrid.

Figure 8.3.3-1 is a timeline of the interplanetary mission and summarizes the orbital support provided by the STDN and TDRS subnets. Individual subnet support is projected in Figure 8.3.3-2 and Figure 8.3.3-3. The following conclusions can be drawn from the timelines, known network capabilities, and the onboard systems capabilities.

- Support provided by the STDN is limited to the hyperbolic burn.

- The TDRS can provide support only to the hyperbolic, and retro burns, since the ascent and circularization burns occur in the zone of exclusion for the mission analyzed.

- The STDN does not enhance network support for the Tug.

- If the Tug outputs data at 64 Kbps rates or higher during burn periods and onboard recorder dump periods, the MA system will not sufficiently support the Tug and other users. This will necessitate the need to schedule SSA user service capability. The onboard system must have the capability to interface with both the MA and SSA user systems.

8.3.4 Summary of Communications Support

The STDN ground sites will have the capability to support the 16 Kbps, 64 Kbps and 256 Kbps data rates from the Tug. However, the NASCOM capability from the STDN ground station to the Tug operations centers have not been specified.

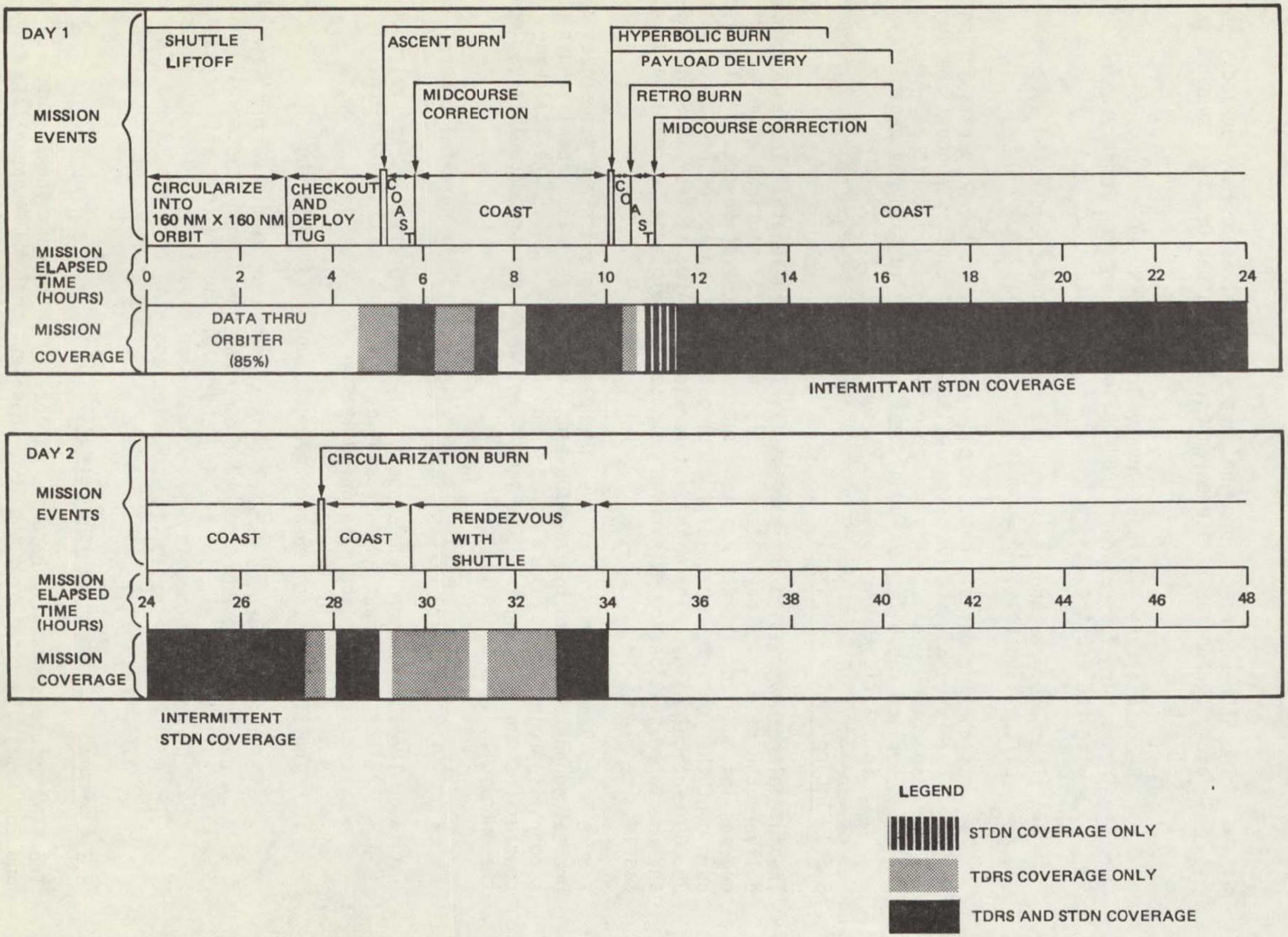

Figure 8.3.3-1. Tug Interplanetary Mission Timeline (TDRS/STDN)

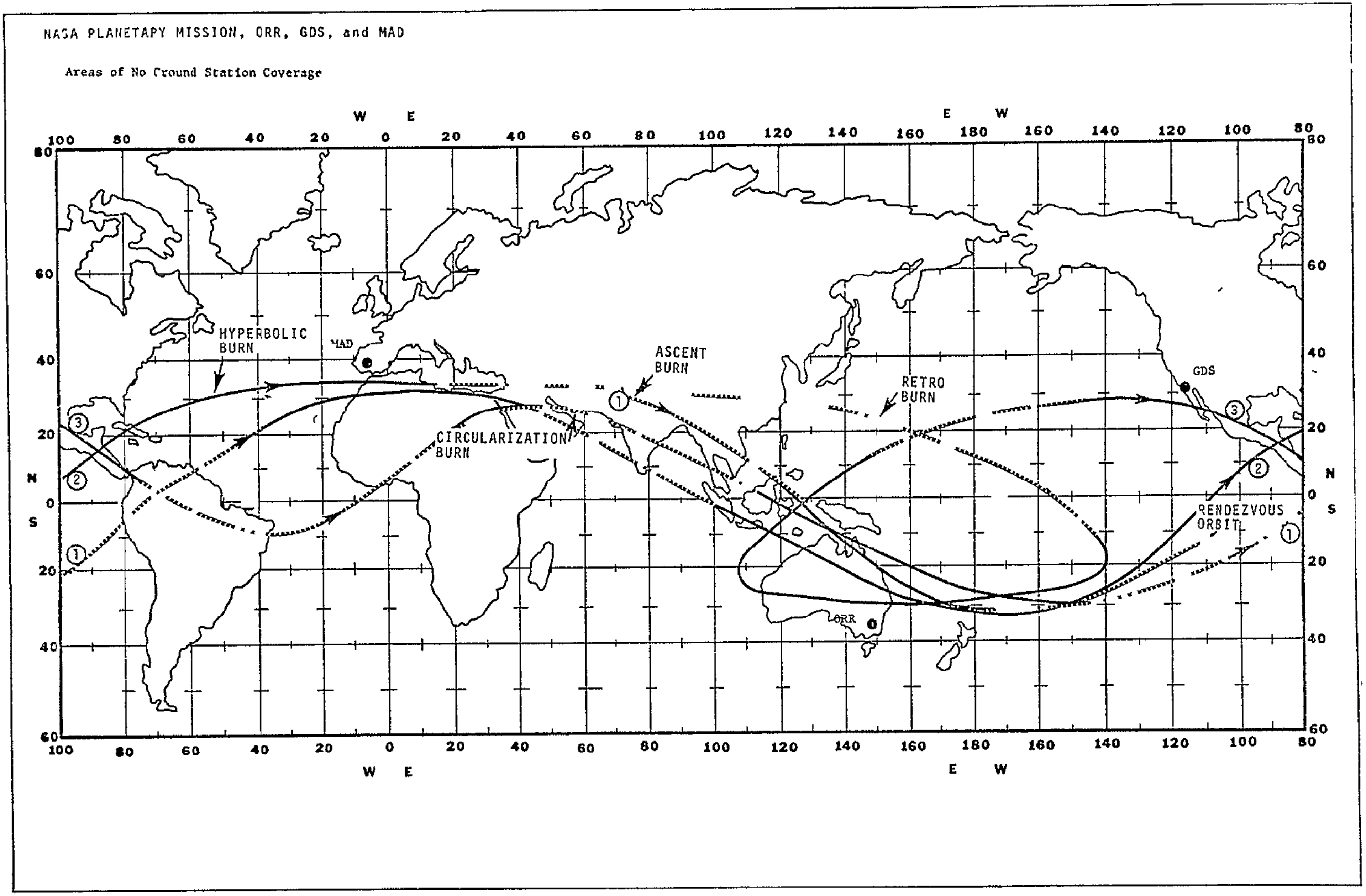

Figure 8 3 3-2 Tug Interplanetary - STDN Only Case

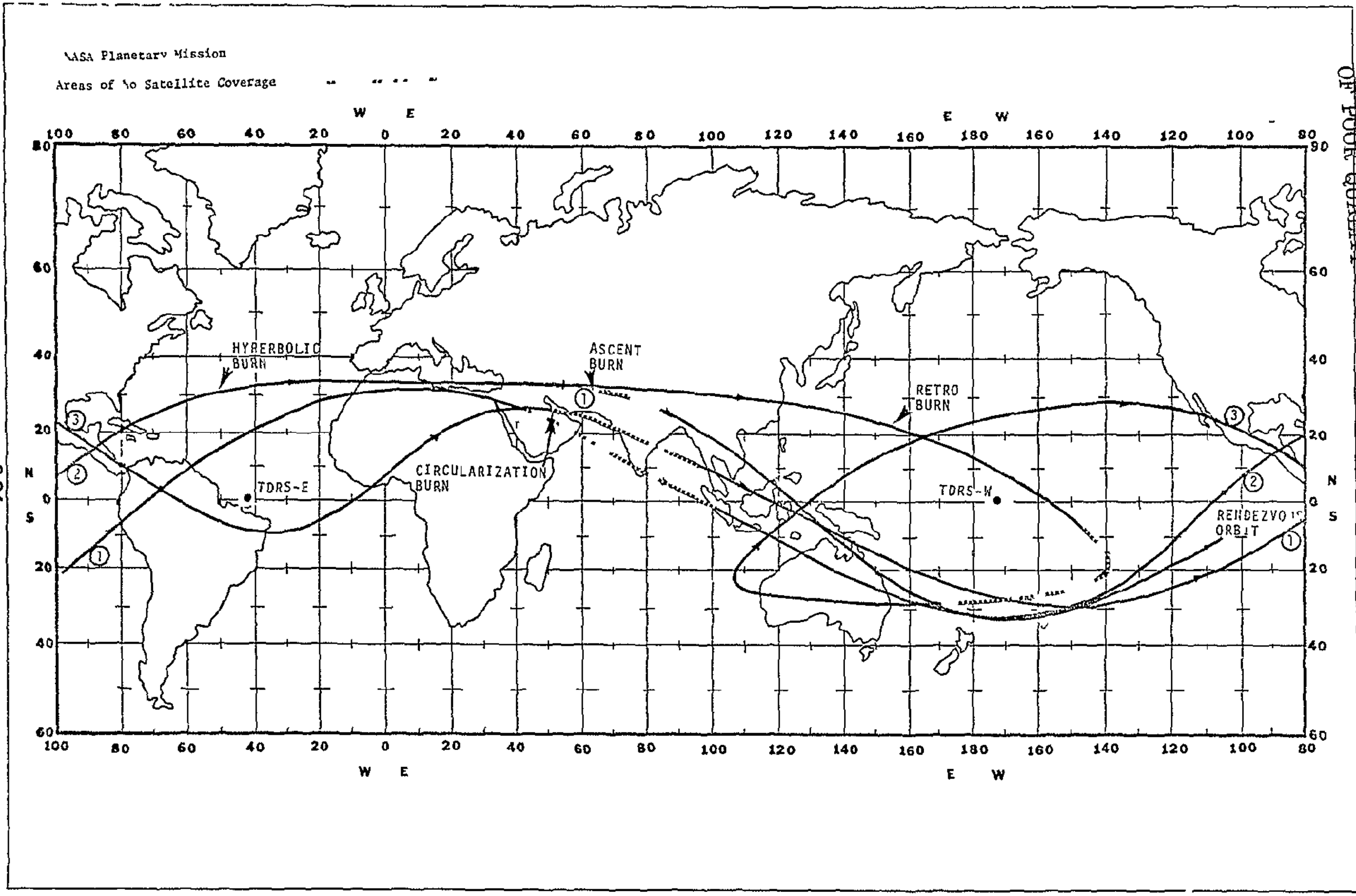

Figure 8 3 3-3 Tug Interplanetary - TDRS Only Case

Based on today's standards, 16 Kbps is possible in real time, but the 64 Kbps could not be supported without modification to the rate.

The TDRSS user support requirements will be varied. For instance, the Tug 16 Kbps requirement can be met by the Multiple access system However, a 64 Kbps requirement during burn periods may preclude the use of the MA system by the Tug, primarily because bandwidth requirements would limit the use of the TDRS MA system by other users The same reasoning applies to the onboard recorder dumps, which is expected to be at 64 or 256 Kbps The most obvious solution is to require the Tug to interface with the S-band single access system during burns and onboard recorder dumps At this time the MA user can interface with the SSA system with a minimal hardware impact However, this should be pursued in greater detail due to the significance of the requirement

Mission planners are advocating the use of a 256 Kbps TM link during burn and post burn periods The S-band single access user services and the Ku-band single access user services can provide the required capability only. This would preclude the user of the Multiple Access system The SSA concept is similar to the MA concept, however, the number of simultaneous users is limited as well as the means of the TDRS to provide support Future mission planning activities should assess the availability of the SSA systems for Tug, realizing that one TDRS can support only two SSA users simultaneously.

The addition of ORR and GDS add sigificantly to the high altitude orbital missions coverage (interplanetary and geosynchronous) for which they are configured MAD support is significant only during the geosynchronous missions. A limited ground network (STDN) will not be adequate to support a broad spectrum of low altitude missions These missions can best be served by the TDRS

It is also recommended that the ground support and RF requirements be written to the next level of detail. This will accomplish two things, (1) impact the requirements against the onboard systems design, and (2) provide a baseline for a more indepth support network analysis Support requirements should also be prioritized to gauge their impact, mandatory, highly desirable, desirable, and etc.

The study provided network coverage times based on simplistic earth-vehicle-TDRS geometrical considerations only. Further studies should consider other variables as mentioned in Section 8.2 1.

- Keyholes
- Terrain
- Handovers
- Vehicle attitudes
- STDN capabilities (must be defined first)
- Vehicle antenna occulations

8 3 5 Representative Network Loading

The network loading created on the STDN/TDRS was determined based on several assumptions

- If the ground station was in line of site of the vehicle it supported the mission.

- The Tug mission model presented in the Baseline Space Tug Flight Operations Document is representative of the actual missions flown

- The Sun Synchronous, Interplanetary, and Geosynchronous missions are representative of these missions

The typical mission model presented in the Baseline Space Tug Flight Operations document gave a total of thirty-one Tug missions (deploy and/or retrieve) to be flown in 1984 This total was made up of three categories of missions and is represented in Figure 8 3 5-1

- Geosynchronous - 14 missions

- Earth orbital - 12 missions

- Earth escape - 5 missions

The three missions analyzed to obtain network loading data were assumed to provide average loading data for all other missions within their respective category The missions analyzed were

- Geosynchronous (GS)/geosynchronous

- Sun synchronous (SS)/earth orbital

- Interplanetary (IP)/earth escape

The resulting average yearly loadings per station were a total of the hours required per station for support of the three missions analyzed Rosman (ROS) and Merritt Island (MIL) had nearly duplicate coverage, while Alaska (ULA) provided minimum coverage The minimum station network configuration that could provide economical coverage for the three different types of missions consist of Madrid (MAD), Orroral (ORR), Goldstone (GDS), TDRS-East, and TDRS-West Additional analysis of the remaining Tug missions would be required to identify the optimum network configuration for Tug.

8.4 OPERATING MODES OF MISSION CONTROL

The Space Transportation System is a vast integrated operation within which is embedded a facility for the real-time control of the Space Tug operations Figure 8 4 0-1 illustrates the five fundamental control centers which must act together to effect the maximum efficiency of operations.

Each of the designated facilities has its own particular requirements The Spacecraft Operations Center (SCOC) is responsible for the monitoring, commanding and controlling of the Spacecraft systems which support the scientific

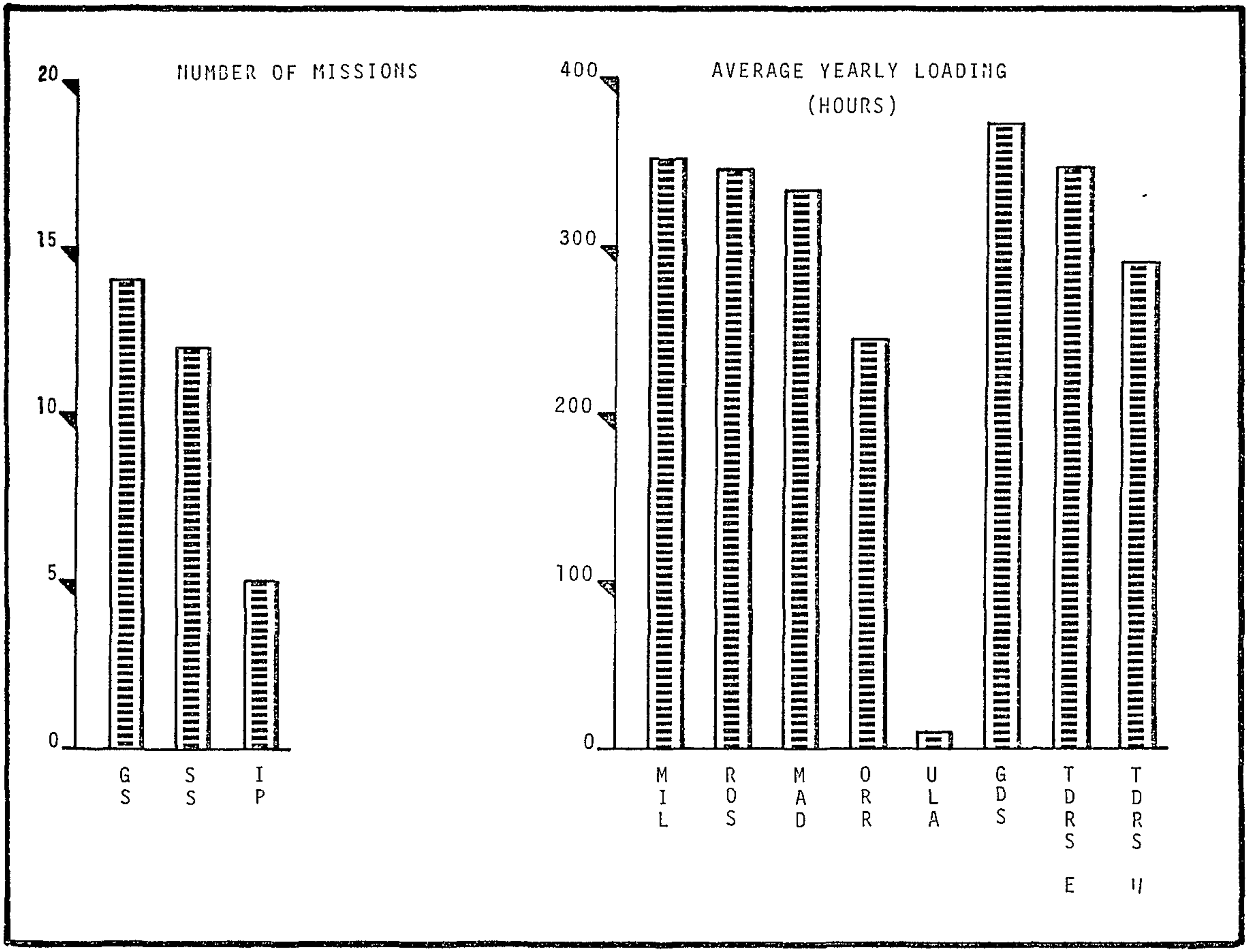

Figure 8 3.5-1 Network Loading 1984 Tug Missions

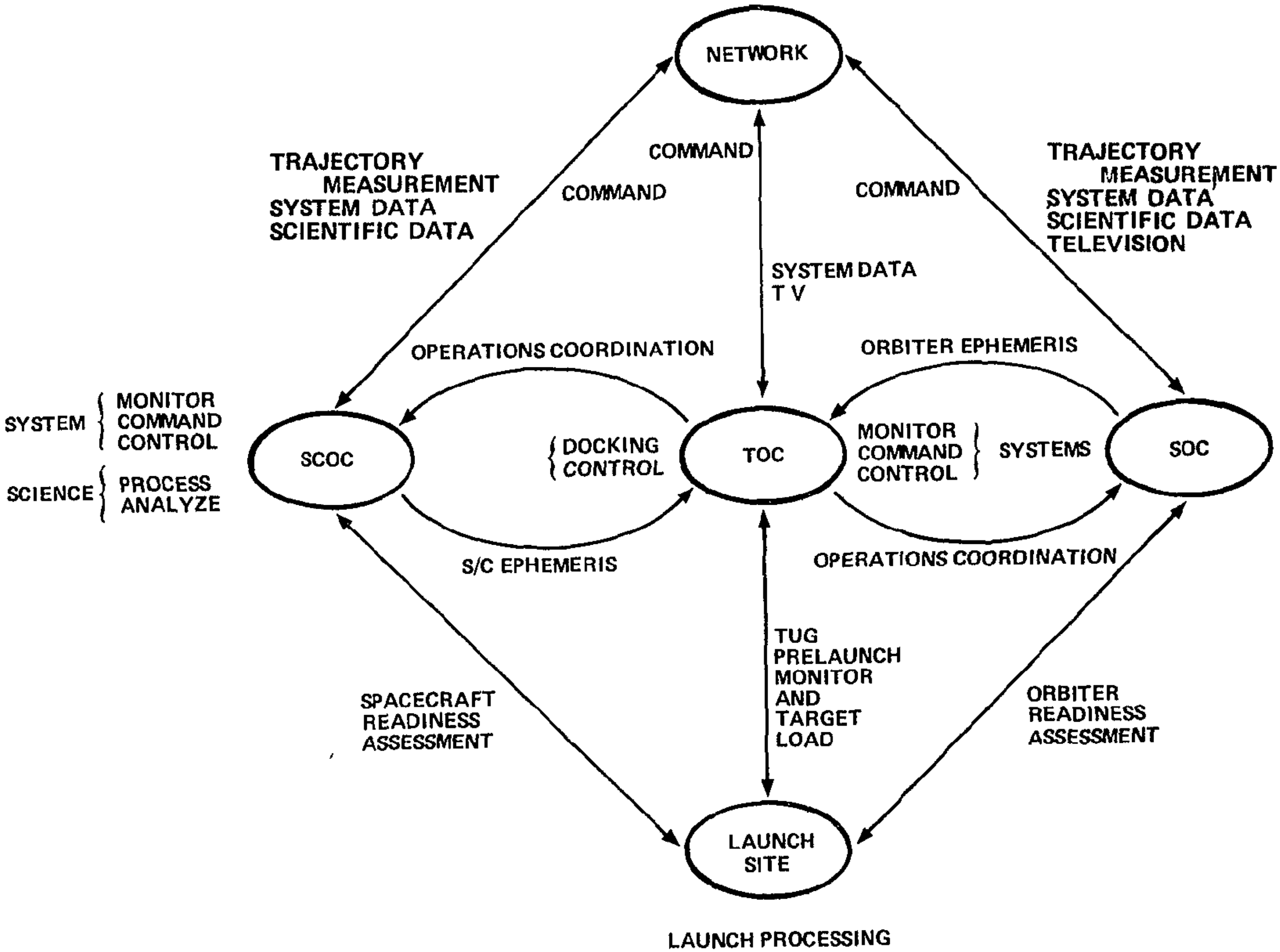

Figure 8 4 0-1 Space Transportation Control Center Interfaces

payload and for maintaining knowledge of the Spacecraft ephemeris The Spacecraft Operations Center is also responsible for the control, processing and analyzing of the scientific data derived from the experiments carried by the Spacecraft The type of data coming into the Spacecraft Operations Center relates to the trajectory, a limited amount of systems performance data and a large quantity of scientific data The outgoing information from the Spacecraft Operations Center consists fundamentally of commands to the Spacecraft and voice coordination with other centers within the operational complex A specific exception is the providing of Spacecraft ephemeris data to the Tug Operations Center

The Space Shuttle Operations Center (SOC) will be responsible for monitoring, command and control of the Space Shuttle Orbiter vehicle and the attached payloads, with primary emphasis being placed upon crew safety operational requirements. The information supplied to the Shuttle Operations Center consists of trajectory measurement data, some system performance information and scientific data from those experiments which are carried onboard the Shuttle During early phases of the flight, the Shuttle Orbiter trajectory will be utilized to provide initial phasing for the Space Tug trajectory, therefore, it is required that the trajectorial information is provided to the Tug Operations Center (TOC). During the retrieval operation, wherein the Space Tug is being recovered by the Shuttle, the inverse is true. The Space Tug will provide ephemeris information and operations coordination with the Shuttle Operations Center

Of the three control centers, the Tug Operations Center has the most complex mission to perform. The Tug Operations Center operation is equivalent to the combined control of the SIVB/Instrument Unit in the unmanned configuration Since there are no astronauts to assist in the control of the vehicle, complete system information and analytical capability must be maintained on the ground or integrated into the onboard data management system

The network, consisting of the TDRS and the STDN for NASA missions, is charged with the responsibility of routing data to the appropriate control center in usable format. At some point the downlink data stream must be split apart and segregated into scientific data routed to the Spacecraft Operations Center, scientific and system data routed to the Shuttle Operations Center and detailed systems data routed to the Tug Operations Center The network must also provide tracking information to all three centers

8.4.1 Prelaunch Operations

Space Tug Operations Center/Launch Site Interface - The Tug Operations Center (TOC) maintains a prelaunch interface with the launch site. In the prelaunch period, the Tug Operations Center will monitor prelaunch systems testing from an informational and backup standpoint In some tests, such as command checkout and target loads, the Tug Operations Center will play an active role The control center will not act in other than an advistory capacity to the launch operations center during most prelaunch testing

Figure 8.4 0-1 presents the Tug Operations Center/launch site interface flow during prelaunch periods. There is no post-launch interface with the launch site

The primary purpose of the launch site is preparation of the Spacecraft, Tug and Orbiter for launch operations The interface with the Tug Operations Center can include any and all aspects of systems readiness, verification and preparation The launch operations center will acquire, process and analyze prelaunch data, and will provide that data either in real-time or near-real-time to the Tug Operations Center for analysis and concurrence The countdown will be conducted at the launch site

Prelaunch Tug Operations Center/Shuttle Orbiter Operations Center Interface - The Tug Operations Center (TOC) will interface with the Shuttle Operations Center (SOC) during prelaunch for systems coordination purposes The Tug requires all systems be monitored at the TOC There will be minimum dependence upon the Orbiter crew for any functions other than caution and warning monitoring No prelaunch tests of system performance will be conducted by the Orbiter crew Since the Orbiter crew will be in contact only with the SOC, any system functions of the Tug which change the status of any parameter displayed to the astronauts must be pre-coordinated through the SOC air-to-ground voice loop There will be no direct voice contract between the Tug Operations Center and the Orbiter crew

Prelaunch Tug Operations Center/Spacecraft Operations Center Interface - During prelaunch operations, the focus of activity is on the launch site, Orbiter and Shuttle Operations Center The Tug Operations Center and Spacecraft Operations Center perform backup and monitoring functions only The Spacecraft Operations Center is primarily concerned with Spacecraft readiness, while the Tug Operations Center performs the same assessment

There are some potential Spacecraft/Tug physical interfaces which require operations coordination to ascertain the system operability

Prelaunch TOC/Network Interface - The network will acquire real-time telemetry and provide a command interface during prelaunch operations through a ground site located near the launch operations center.

The Tug Operations Center will generate commands through the network to the Tug, and will monitor feedback from the Tug over the RF links

All operational interfaces between the Tug Operations Center and network will be verified during the prelaunch phase.

8.4 2 Predeployment Operations

Tug/Shuttle Operations Center Predeployment Interface - The Tug Operations Center monitors all downlink data from the Tug, and acts as back-up analysis to support Orbiter-derived Tug concerns. Any communication with the Orbiter crew will be through the Tug Operations Center/Shuttle Operations Center coordination loop. There will be no direct astronaut/Tug Operations Center communication Figure 8.4 0-1 presents the Tug Operations Center/Shuttle Operations Center predeployment interface

The Shuttle Operations Center functions are devoted primarily to the control and monitoring of the Orbiter vehicle, with some effort being devoted to the Spacecraft and Space Tug Caution and Warning functions

Primarily the Shuttle Operations Center will monitor the Orbiter launch, provide voice communication with the crew and real-time data analysis during the boost phases.

Following insertion into low earth orbit, the Shuttle Operations Center will be responsible for managing the Orbiter trajectory, not only during the time period for shaping the Space Tug phasing, but also during the subsequent phases of the mission during which Shuttle onboard particular experiments are being conducted.

During all phases, the Orbiter system will be monitored for proper performance and voice communication established with the crew for the purpose of coordinating system condition information.

The Shuttle Operations Center will be deeply involved in alternate missions and contingency operations and support, including recovery, landing and rescue operations.

Primary responsibilities will center around crew safety involvements of the Space Transportation System.

TOC/SCOC Predeployment Interface - At this time, the Tug and the Spacecraft are still secured within the Shuttle Orbiter cargo bay There is no significant difference in the operations in the prelaunch and predeployment periods regarding the interface between the Spacecraft Operations Center and the Tug Operations Center Operations coordination is required in order to advise the Centers of on-board events which may change the status of their displays

TOC/Network Predeployment Interface - The Network provides support to all control center operations. The network acquires, processes and distributes data to the control centers The primary functions of network data support are to schedule the network facility to meet the particular program, experiment, and vehicle support requirements

The network interface with the Tug has been verified in the prelaunch period The interface between the network and the Tug Operations Center in the predeployment period provides the information to the Tug Operations Center which was provided by the launch site in the prelaunch period. The primary function is to monitor system data and provide backup information through the Spacecraft Operations Center to the astronauts in the event of operational coordination requirements.

8 4.3 Post-Deployment Operations

The Orbiter crew will monitor and control the Tug systems performance during all cargo bay manipulator arm and near-in operations where there is a crew safety involvement After deployment, however, the operational interfaces become somewhat more complex

Figure 8 4 0-1 illustrates the Tug Operations Center/Shuttle Orbiter Operations Center post-deploy operations

TOC/SOC Post-Deployment Interface - Data is provided to both the Shuttle Orbiter Operations Center and the Tug Operations Center and the Orbiter crew relative to the Tug systems condition Any command action undertaken by the Tug Operations Center must be pre-coordinated through the Shuttle Operations Center to the Orbiter crew so that any change in system status indications will not be unexpected The immediate post-deploy time frame is critical to mission success and will require extreme team work and coordination activities Trajectory measurement information will be supplied to the Tug Operations Center through the Tug Telemetry System Trajectory measurement information will be supplied to the Shuttle Operations Center from ground based sources During the immediate post-deploy period, there exists an opportunity to compare Tug and Shuttle navigation state vector information

TOC/SCOC Post-Deployment Interface - At this point in time, the Spacecraft is still a passenger aboard the Tug vehicle System data from the Spacecraft will be provided to the network through the Tug downlink and, in the network, will be distributed to the Spacecraft Operations Center, where it will be assessed and analyzed There exists the potential that a command uplink will be required to issue corrective actions to the Spacecraft systems No command action may be taken to the Spacecraft without pre-coordination with the Tug Operations Center The Tug Operations Center will be monitoring Tug parameters and a selected set of Spacecraft parameters

TOC/Network Post-Deploy Interface - In the post-deploy operations, the network will receive and process systems data for the Tug Operations Center, and will provide a command uplink capability between the Tug Operations Center and the Tug vehicle Command two-way lock is required during all mission phases other than while the Tug is in the orbiter cargo bay The network will provide real-time data routing and distribution to all user agencies The network will also provide a catalog of, and maintain historical data archieves for, all programs

8 4 4 Spacecraft Deployment Operations

Figure 8 4 0-1 illustrates the Spacecraft deploy operations coordination loops The Tug mission will have carried the Spacecraft to the planned deployment location Since there exists no capability for communicating with the Spacecraft after separation, the only Tug function is to provide a stable attitude and establish pre-deployment conditions for the Spacecraft prior to totally losing contact with it

The Spacecraft systems will be activated by the Tug either automatically or through ground command prior to separation Upon activation, the Spacecraft will begin communicating trajectory, system data, and scientific data to the Spacecraft Operations Center The Spacecraft will also be prepared to accept command uplink data through the network, if that capability has not existed

previously during its role as passenger on the Tug The primary coordination problem is in ascertaining that the correct predeployment conditions have been reached by the Tug This requires operations coordination between the Spacecraft Operations Center and the Tug Operations Center, particularly in the comparison of ephemeris achieved versus ephemeris desired. The Spacecraft will be visually inspected by the Tug T.V System

Once separated, the Tug will phase away from the deployed Spacecraft. Following a successful phasing maneuver, the Tug will retro-fire and establish a phasing orbit preliminary to meeting the Shuttle for recovery

8 4 5 Spacecraft Docking/Retrieval Operations

Some missions will require the Space Tug to rendezvous with and establish a mechanical lock with an orbiting Spacecraft The rendezvous may be accomplished by using established phasing and co-elliptic techniques. The unproven aspect of the mission is in the terminal rendezvous and docking components

Figure 8 4 0-1 illustrates the coordination loops between the operations support elements which are active during terminal rendezvous and docking

It is within the capability of existing technology to dock in a completely unaided manner. However, there is a natural reluctance to completely turn over docking to hardware There will be television (slow scan) provisions on the Space Tug vehicle which will permit ground monitoring of the docking

The Space Tug is the active vehicle in the rendezvous and docking sequence During the docking and retrieval operations, the Spacecraft Operations Center will provide engineering surveillance to monitor Spacecraft systems and provide command support as required

8.4.6 Space Tug Retrieval Operations

Figure 8 4 0-1 illustrates the coordination loops active during Space Tug recovery by the Space Shuttle.

The Space Tug Operations Center will receive an ephemeris of the Shuttle Orbiter, or, equivalently, target pre-settings, from the Orbiter Control Center prior to beginning the final retrieval sequence

The Space Tug will compute the optimum maneuver sequence to meet the Orbiter with the targeted differential height and phase relationship. This computation will be verified by ground sources at the TOC, and altered by uplink command if significant variance is detected. Normally, the Space Tug will maneuver to the targeted orbit without ground intervention.

Having achieved the waiting orbit, the Space Tug systems will be deactivated. Ground monitoring will verify deactivation The Space Tug will be the dormant vehicle during recovery When the Shuttle Orbiter is within 20 miles range, communication can be established with the Tug. The operation then becomes

the primary responsibility of the Orbiter crew and the SOC The Tug Operations Center continues to monitor the Space Tug through the recovery operation and to advise the SOC as necessary

When the recovery operations are over and the Tug (with or without Spacecraft) has been secured in the orbiter cargo bay, the Tug will be inactive through landing The TOC monitoring function will cease when Tug telemetry is no longer available

8 4 7 Landing Operations

No operational requirements have been identified that apply during the landing phase

8 5 CONSIDERATIONS FOR "NEW BUILD" CONTROL CENTER DESIGN

The objective of this task was to identify development concerns incurred during the establishment of NASA/DoD Mission Control Centers All elements of the Mission Control Center development activity were addressed, with existing approaches identified, so that developmental problems could be avoided in defining the IUS/Tug operations concepts, functions, and plans Several center/programs were assessed for requirements, such as, staffing, computer capability, software, hardware and facility Those centers included are JPL-Deep Space, AMES-Pioneer, JSC-Apollo and Gemini, GSFC-Unmanned Satellites and the Air Force Satellite Test Center (AFSTC)

8 5 1 NASA/JSC Development Concerns

8 5 1 1 Operational Philosophy

Prior to discussing any development activities, it is benefical to understand the operational objectives and environment of each center JSC is currently configured (as in the past) to support missions of relatively short durations on an infrequent launch basis

The JSC Mission Control Center and associated tracking stations are set up as a system rather than project oriented, therefore, it is reconfigured from project to project Occasionally part of the system (i e , control console, displays, memory systems) are updated or upgraded, however, an attempt is made to normally have the resources required to support a project, rather than modify the MCC into a project specific configuration When equipment is acquired to support a project, a growth factor is added whenever possible to accommodate future requirements

8.5 1 2 Systems Configurations

The basic MCC consists of the Real Time Computer Complex (RTCC) composed of five IBM S360/75's on parallel input and output busses, console areas for flight controllers, network controllers (STDN), and instrumentation controllers Real time processing is a major MCC effort The second largest effort is system validation and training The RTCC is used 99 percent of the time in these roles, with one percent of the total utilization spent on actual flight support The third largest effort is the off-line data processing by other computers, Univac 1108, however, the RTCC computers provide the interface for this data as input to JSC from the remote sites

To alleviate scheduling problems, NASA writes a development plan for each major MCC change This plan assures a close coordination of the contractors and government and is closely followed and reviewed to identify problems at an early stage A need was developed for extensive software configuration planning and development control.

Some development concerns were created outside the realm of the MCC, however, a direct relationship exists from data acquisition by the onboard sensor to data processing at the MCC. This resulted in a major problem in ground telemetry processing caused by the non-uniformity of onboard data communication systems. An indexing counter in the main frame would simplify the ground decommutation process in many cases, however, it was not provided because it is not required for onboard commutation. NASA should coordinate the commutation and decommutation developments to reduce the total cost of data processing

8.5.1 3 Roles and Responsibilities

There are about 160 NASA people and 900 contractor personnel active in the JSC MCC operation. IBM is the software contractor and integrator for the RTCC, and Philco Houston Operation (PHO) is the hardware integrator and system Maintenance and Operations contractor for all except the RTCC. Various manufacturers provide contracted maintenance on their data processing equipment NASA retains the system integrator and system engineer roles, and additionally supplies facilities and precision measurements and equipment laboratories

8 5.1 4 Identified Design/Development Concerns

Further evidence of the end to end impact of processing on the data flow system occurred during the Gemini mission. It was found that the command uplink had been designed to give a very low error rate (redundant commands, encoding, high gain antennas, etc) while command verification was based on a two watt transmitter in a high error rate link. The result was that errors in the downlink caused the MCC to transmit many commands unnecessarily

JSC committed early in the development stage to reconfigure the RTCC by software changes when signal sources varied between missions. In some instances, where there was a minimum time between launch centers and significant requirement for support, simulation, or training, software changes were not possible and wiring changes proved more feasible. Software freezes caused subsequent reconfigurations to be made by rewiring the data inputs to the RTCC's. Wiring changes were selected because of simpler validation and less man hours

The MCC/User interface needs attention to assure that anomalies in the experiment are understood by the personnel creating the telemetry reduction software In essence, the software was designed to operate with less than perfect data. Rather than requiring simple software changes, such as change coefficients, software required more extensive programming efforts, revalidation, etc. If software were more flexible, the software quality assurance effort could then identify immediate products in the processing needed to assure that discrete steps are properly implemented. In many other cases, the user stated his requirements without considering the processing load involved (color imagery vs black and white), which resulted in a reduced utilization of the MCC resources.

8 5 2 NASA/JPL Development Concerns

8 5 2 1 Operational Philosophy

The JPL Mission Command and Control Center (MCCC) is viewed as a support service to the various deep probe programs offices "Institutional Software" at JPL performs the actual communications functions with the Deep Space Network (DSN) sites in Spain, Australia and Goldstone, California Other "institutional" routines for orbit planning, video and telemetry reduction, and command generation, are available for use by the probe program Mariner (JPL) is controlled in the JPL Mission Test Control Facility (MTCF, Univac 1218, 1230 and 116 computers) Pioneer is controlled at NASA Ames (Xerox Sigma 5s and PDP 11s) Viking (NASA Langley) will be controlled at JPL, and Helios at Munich, Geormany As a result JPL builds some spacecraft, e g , Mariner, and functions as the data gathering and communications center for the probe controllers, wherever they are located It also provides institutional software and computer resources to the requesting Project Offices, but spacecraft control resides with the builder, not the DSN

8 5 2 2 System Configuration

The MCCC consists of three computer complexes, the Mission Computing Center Facility, (MCCF, three IBM 360/75), the General Purpose Control Facility (GPCF, a Univac 1108), and the MTCF used for Mariner The DSN has 210 foot and 85 foot dishes at each of three locations, with high (117 Kbps), medium (51 2 and 22 05 Kbps), and low (2 4 and 4 8 Kbps) rate data lines connected to an IBM 360/75 in the MCCF During operations, two 360/75s share the data lines and computing, although only one set of outputs is used (hot switching to backup is possible) The MCCF handles command bit structure generation and data packing/unpacking in real time, with up to six data lines simultaneously The unpacked telemetry may be routed to the GPCF, MTCF or other operations control centers The 1108 computer performs orbital planning and control, while the 360s are primarily real time processing machines, with resident software freezes before operational contacts to assure software integrity. The long time-line in JPL missions allows development of operational software after spacecraft launch, so that 360 software development, testing and validation is a continuous process at the MCCF, generally on the third (offline) machine Attached to the DSN before the data enters the MCCF is a network control computer, which continuously monitors data quality and constructs a Master Data Record, to duplicate the Original Data Record at the site

8 5 2.3 Roles and Responsibilities

Jet Propulsion Labs of California Institute of Technology is a NASA contractor, and other NASA, government and JPL contractors reside at JPL Philco-Ford is the JPL subcontractor operating in the data services division for manning and operating the Goldstone Complex with 1000 people The 4000 total JPL employment includes spacecraft designers, builders and system engineers for the DSN The role of JPL is different from probe to probe, as is the utilization of the JPL/DSN resources. The different probe efforts utilize the MCCF and JPL data services to different extents, depending on the size and talents of the probe program office and their support contractors As an example, Pioneer 6 through 9 installed telemetry processors at the DSN sites to reduce telemetry and transmit it via TTY to NASA Ames, where analysts

could telephone the MCCF to have commands transmitted For Pioneers 10 and 11, the telephone has been replaced by a data link from the Ames Sigma 5 through its PDP 11 to the JPL 360/75. This link also carries the Pioneer telemetry. The DSN sites operate as a "bent pipe" and no longer perform telemetry reduction

8.5 2 4 Identified Design/Development Concerns

The software freeze on the 360/75 for an operation impacts software development/testing for the programs The Support Instrumentation Requirements Document (SIRD), which levies support requirements on JPL and the DSN, should be expanded to show expected freezes in the timeline of each probe's associated software development cycle JPL allocates resources by committing themselves to the SIRD requirements

Software testing has expanded from five men to 30 to reflect the intricate software relations in the 360/75 computers and to give more confidence in software development

Scheduling is accomplished by resource - DSN, MCCF, GPCF and MTCF, so that a space probe office must schedule each resource weekly, rather than put the input into a network scheduling office which would combine all requests for all resources High priorities are allocated to operations and state of health problems, so that the remaining operational problems are of a low level nature, but can impact software development

8.5.3 Pioneer Mission Operations Control Center Development Concerns

8 5.3 1 Operational Philosophy

The Pioneer Mission Operations Control Center (PMOCC) capabilities have been developed to control two Spacecraft (SC), Pioneers 10 and 11. Because the Pioneers are nearly fly-by-wire, most changes in the SC are commanded from the ground. Only a few emergency shutdowns are accomplished automatically by the SC This imposes real-time state of health monitoring of every SC subsystem on the MCC. To meet this requirement, pre-programmed command sequences to shut down a subsystem are stored at the MCC and at each Deep Space Network (DSN) station. Extensive DSN loss of communications procedures are necessary to preserve the SC in the event of MCC-DSN communication outages With a one way RF delay of 50-60 minutes, there is time for the MCC to call SC subsystem specialists in to help on equipment problems while pre-programmed commands are being set The large round trip delay and fly-by-wire nature of the SC have caused the MCC to be designed around real time state of health checks and having/updating elaborate contingency command plans to "safe" the SC until a subsystem specialist can perform detailed evaluation of the subsystem "Quick look" telemetry reduction is performed in the MCC for functional command verification This includes gain changes, telemetry mode changes, attitude and control system configuration changes, etc.

The MCC was designed from the start (it is a converted conference room) for the Pioneer Mission, and for budgetary reasons maximum use of prelaunch ground test computers for flight support is a driving concept. The same office that operates the PMOCC also acquired the spacecraft, therefore, the systems contractors were responsive to developing the ground test fixtures for their dual roles

8 5 3 2 System Configuration

The PMOCC has three Xerox Sigma 5 computers, two of which were used for Spacecraft checkout, and two PDP II communications concentrators A Sigma 5 and PDP II are dedicated to each Pioneer, with the third Sigma 5 performing offline processing, with the capability to be switched to online real-time support The system has evolved from heavy reliance on JPL 360/75 computers for DSN site support to performing all real time functions in the PMOCC, with JPL providing metric orbit reduction and calculations for course changes This change was made to reduce the effects of software freezes on the JPL 360/75 caused by a critical phase of any of the Spacecraft sharing the DSN The JPL 360/75 has resident routines supporting each of the Spacecraft, and it has been necessary at times to freeze all software development in order to prevent changes on the program's software from disrupting the computer during a critical portion of another program's flight Moving this application software to the PDP II and Sigma 5 has minimized the impact of these freezes on PMOCC software development The real time support positions are a controller for each Pioneer and a technical assistant for both These personnel command, read telemetry, and assure state of health of the SC Offline processing of Master Data Records for the DSN sites is performed around the clock Experimenters and subsystem specialists are on call, and perform other functions while the Spacecraft are in the cruise mode The manning jumps during contact periods, and the offline processing changes to provide "quick looks' at subsystem data The intent in the PMOCC design is to provide the minimum resources necessary to do the job, with a large cross-pollenization among the center personnel

8 5 3 3 Roles and Responsibilities

The Pioneer mission is a typical case where the Space Project Office (SPO) procures both the spacecraft and the ground data processing system, with JPL and the DSN providing the data collection resources Present NASA mission operations personnel number 20, with 52 Bendix support people in four groups Flight Operations, Data, Mission Analysis, and Launch Operations. Flight Operations are the controllers and technical assistants, performing SC control, real time telemetry readout of the science and SC equipments, and real time interfacing with JPL and the DSN The Data group operates the computers, and accomplishes hardware and software development to support the mission The Mission Analysis and Launch Operation groups have various roles that change with the mission phase Both NASA and Bendix are flexible in the roles that the offline personnel perform as the mission progresses The software is unique to PMOCC, and has been developed by the SPO, including the launch support software The hardware has been salvaged, rented and contracted for, with manufacturer maintenance wherever possible The maintenance contractor performs all modifications to his equipment. Bendix performs system maintenance mods, interconnects, etc , to the equipment otherwise unsupported These include the consoles, bit syncs, and telemetry station

JPL's role is that of data gatherer and DSN interface, and also provides the use of high cost resources, such as the orbit determination and some image processing equipment

The trend has been to concentrate the real time functions at PMOCC, minimizing dependence on the JPL computers for DSN support A major problem is DSN

resource allocation, with several programs requesting maximum data receipt, and the many programs competing for the same resources Weekly scheduling meetings handle normal conflicts, with real time changes when a Spacecraft's health is threatened. This forces the Pioneer Mission Office to gather weekly requests from the scientists as inputs to the scheduling process. There is a DSN operations control center at JPL in voice contact with the stations, but normally PMOCC is in voice contact with JPL, and not the sites

8.5.3.4 Identified Design/Development Concerns

Resource allocation at JPL has caused PMOCC to become self-reliant wherever possible Although duplicating existing capabilities, by having them at PMOCC, the SPO has gained development resources that would normally be shared if at JPL.

The flexibility of the NASA staff is a response to the shifting workload in PMOCC and is an effort to broaden in-house capabilities

8.5.4 NASA/GSFC Development Concerns

8 5 4.1 Operational Philosophy

NASA GSFC has been developed to support satellite payloads. Current design objectives are to standardize the Multisatellite Control Center (MCC), and to automate configuration changes from one satellite pass to the next. Another goal is to have standardized software and operator interfaces so that modular improvements can be made. The prime mission of the MCC is the health and safety of the SC, with other Goddard divisions handling software, data analysis, orbit reduction, and data reduction.

8 5 4.2 System Configuration

The MCC is built around a digital switch, SCADI, which is really three PDP 11-20s: These provide connections between the computers (XEROS 930s and Sigma 5s), PCM converter decoders, strip chart decoders, CRTs and consoles, and the data lines from the sites Up to 10 simultaneous satellite supports are possible In the past, each console and computer group was custom built for a particular satellite, but the movement to grouping common functions and providing standard consoles is underway. The three SCADI computers function as executive, online and backup, with real time switching possible Simple format conversions are also performed in the SCADI, with an emphasis on automatic reconfiguration of the system as the support load changes. The SCADI also monitors the data blocks from site and performs real time corrections and diagnostics on the data

8.5.4 3 Roles and Responsibilities

RCA is the Maintenance and Operations contractor at the MCC, in a ratio of seven RCA to each NASA person in flight operations. The NASA MCC design staff numbers 15. Goddard requires standard interfaces from the SC builder, with a Support Instrumentation Requirements Document detailing the agreement. This formal document is regularly reviewed and is the vehicle for handling conflicts between SC builder desires and ground capabilities. The level of normal support is herein defined, and requests for more than this must be approved by higher NASA offices.

Wherever possible the SC contractor is asked to develop test software on compatible machines, in a structure so that it can later be used in flight operations Structurally, NASA designates a member of the MCC project staff as user interface, where the definition of ground system processing of SC data is performed in real time This man is also the responsible person for MCC operations in support of the SC To assure hardware/software compatibility, the Control Center Systems Managers have complimentary backgrounds, and both must initial design reviews of all hardware and software developed for the MCC No new software development is allowed until the specifications for the changes are approved, and the interfaces defined

8 5 4 4 Identified Design/Development Concerns

The GSFC MCC has become conservative in technology utilization, reflecting a small budget

A Digital Data Processing System, a minicomputer with large disk storage, is being procured to allow post pass playback of the entire pass over low quality voice lines. This system will eliminate the shipping of range tapes in most cases

Unplanned MCC processing changes are handled with software changes wherever possible, reflecting the shorter development cycle of minor program changes

The MCC design is frozen about 3 to 4 months before launch to allow 30-45 days for operator training and another 30-60 days for simulation and rehearsals This early freeze has become necessary to confidently assess MCC readiness Changes are allowed only at times agreed to by the M&O and NASA staffs This freeze provides a system baseline early enough to make the necessary changes

Two basic questions in MCC development are "What are the real requirements?" and "When is it really ready?" The designated member of the project staff to interface with the user, and the MCC design freeze are the GSFC responses to these questions, along with the regular reviews of the Support Instrumentation Requirements Document

8 5 5 DoD/SGLS Development Concerns

This section does not include the operational philosophy and systems descriptions as previously defined at the other centers due to sensitivity of the data. However, a summary of the concerns is described below in general terms

Identified Design/Development Concerns - Several problem areas can be related to other centers as well as the Satellite Control Facility (SFC) Once software tradeoffs had been performed a software freeze was initiated The premature freeze impacted developmental program design as well as changes, integration among contractors, and the relationship of the contractor and his role in the facility

The network does not have the resources to satisfy all support requirements levied by users, primarily due to computer, communications and tracking-station limitations. For months at a time, a Remote Tracking Station (RTS) will have no unscheduled periods if it has the capability to service both polar and equatorial high energy orbit satellites The small on-line

computers have been so heavily loaded in recent years that an emulator system having a five-fold increase in throughput is being procured Eventually the existing software will be replaced by a new software system The number of hours spent in real time support has increased each year, and currently saturates the computer resources The wideband data system, where data rates to 1 024 Mbps are supplied directly from an RTS to a Systems Project Office (SPO) telemetry reduction center, is expected to offload some of the Satellite Test Center (STC) computer requirements

System rehearsals are not as extensive as NASA's, because the missions tend to be evolutionary, with evolutionary software changes to accommodate them The melding of contractor telemetry reduction facilities into the real time loop will be a problem in future rehearsals

In the Advanced Data System era (1967 - 1969), large scale concurrent development of new computers, buffers and software, caused many problems, and an interim software system with minimal changes became the standard system (Model A) Since then, Model A has gradually evolved into the dual computer processor system originally requested in the ADS era This gradual evolution is now preferred for meeting new requirements.

8 5.6 New Control Center Development Approach

The assessment of the mission control centers in the previous paragraphs was based on the particular role of that center and the specific types of missions they supported Several items appear significant in determining the development philosophy for a new control center

Planning and close coordination has been a key to the development of new MCC's Problems were solved more easily in the past by utilization of a detailed development plan and close coordination and review with the developers and implementators Close coordination provided early identification of problem areas and allowed flexibility for long lead time changes

The development plan should specify a system that has growth potential to meet future requirements The upgrading of a system is preferred by a gradual evolutionary process rather than by drastic changes.

The MCC should have the capability to restructure its systems on its own timeline. Or the MCC should thoroughly understand the ramifications of utilizing institutional resources (hardware/software) that may be in contention by other programs. In the same vein, the MCC should not contend for its own resources, i e., software development on a machine that is providing mission support.

The MCC development should be streamlined, deleting redundant operations and development cycles For instance, test software should be developed on MCC compatible machines, such that the software can later be used in flight operations

The MCC should establish a definite interface with other facets of the data flow, NASCOM, GSFC and the STDN/TDRSS subnets The MCC should realize a continued increase in support requirements from other programs may negate those services once supplied by NASCOM or GSFC (Orbit determination), etc.

The MCC should also establish a definite interface with its users, defining the capabilities it can provide and the requirements the user systems must meet to utilize these capabilities This will prevent the user from overloading MCC systems

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SPACE TUG BASELINE OPERATIONS PLAN

IBM

SPACE TUG BASELINE OPERATIONS PLAN 9

A significant number of missions in the Space Transportation System model set cannot be achieved by the Earth Orbiting Shuttle Vehicle This is because its performance capabilities limit it to near-earth missions. To extend the capabilities of the System, an additional stage (Space Tug) has been added to the basic shuttle vehicle

Implicit in the addition of the Tug is the necessity for a ground network and control center for monitoring and/or control of the Tug vehicle during its mission The complexity and, therefore, the development costs of the Tug Control Center, is a function of the requirements resulting from the mission profile and the autonomous capabilities of the onboard avionics of the Tug vehicle

Tug vehicle avionics have the greatest influence on operational autonomy Onboard autonomy establishes the required degree of ground control and monitoring Allocation of functions, such as navigation, influence the avionics requirements From a mission standpoint, this function must be performed, and if not accomplished onboard, it must be done by the ground. It follows that the more autonomous Tug operation permits a decrease in ground operations The following are characteristics of the two autonomy levels

- Level II Autonomy
    - MSFC Baseline Tug
    - Autonomous Navigation (ILT)
    - Rendezvous and Docking Closed Loop thru On-Board Sensors

- Level III Autonomy
    - MSFC Baseline Tug
    - Ground Tracking Required, No Autonomous Navigation
    - Rendezvous and Docking Uses Man-in-the-Loop TV

This section presents the baseline operations plan for a Space Tug vehicle designed for operation at Level II autonomy. The Baseline Operations Plan includes the ground support functional organization, mission controller functional requirements, Orbiter/Crew functional requirements, and operations support requirements Cost estimates are presented for software (ground and airborne), hardware, facilities and services which are directly chargeable to the support of Tug mission operations

9.1 MISSION PLAN DESCRIPTION

This section defines the reference mission which is structured to include the covering set of mission requirements (required mission functions), which provide a basis for selecting and sizing operational support elements

9 1 1 Covering Set of Mission Requirements

Modular timelines were developed which capture the scope of operational activities surrounding trajectory based events Section 3 2 presents and discusses the modules making up the modular timelines It is sufficient for the purposes of this section to note that the reference mission includes all unique operational activities of a Tug mission

The modules are the Orbiter Launch Operations module, which covers the period from launch preparations, Tug deployment, checkout and ready for the first engine burn, the On Orbit Coast module, which covers the interim on-orbit navigation, guidance and control state between active mission modules, the Mainstage module, which is utilized each time a major maneuver is required, the Trimburn module which is utilized whenever the main engine is operated in the tankhead idle mode or pump mode, the Payload Placement module, which covers the activities for checkout and deployment of a Spacecraft, the Rendezvous module, which provides the operations to move from a Coplanar phasing orbit to a point sufficiently near a target spacecraft for docking initiation, the Docking module, which contains the operations from the last braking gate until latch, the Payload Retrieval module, containing the operations for Spacecraft retrieval; the Service module, containing operational functions for Spacecraft servicing, the Orbiter Retrieval module, containing those operational functions performed when retrieving the Tug and Spacecraft, and the Abort module, which contains the operational functions of the Orbiter abort modes.

9 1 2 Dual Deploy - Single Retrieval Mission Timeline

The mission, chosen as the reference for determining control center requirements, deploys two satellites 120 degrees apart at geosynchronous altitude, retrieves a satellite from geosynchronous altitude and returns to the Shuttle rendezvous orbit for retrieval by the Orbiter This mission is depicted in Figure 9 1 2-1 In achieving the objectives of the mission, the Space Tug vehicle must be controlled for approximately 15 maneuvers during a seven day period

Figure 9 1 2-2 presents the major events and combined TDRSS/STDN Coverage timeline for the out-bound phase of the reference mission

9 1 3 Ground Coverage

Since all ground based operations are totally dependent upon the transfer of information from the subject vehicle (in this case, Space Tug) to the ground control and monitoring site, it is significant to evaluate the ground coverage communications capabilities available.

Two systems will be operational during the Space Tug era TDRSS (Tracking and Data Relay Satellite System), and STDN (Spacecraft Tracking and Data Network) Figure 9 1.3-1 presents the ascent and return ground track, with the areas of communication coverage indicated by the solid line for the TDRSS only Figure 9.1 3-2 presents the same data for the STDN-only case An over-lay of the two coverage maps indicates that both TDRSS and at least 3 stations of STDN (Madrid, Goldstone, Orroral) are required for total communication coverage, and that gaps exist in the coverage of either system viewed independently

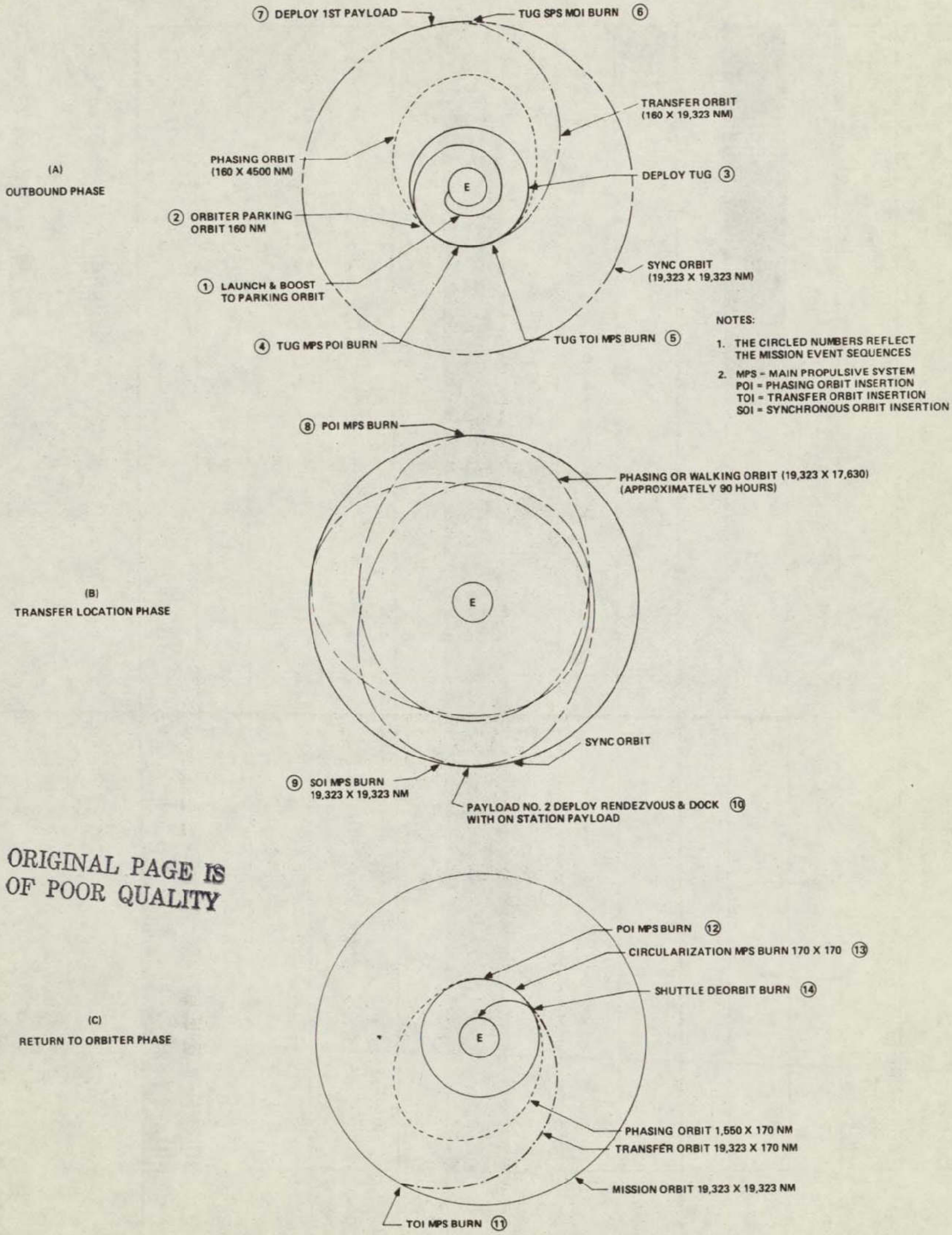

Figure 9.1.2-1. Reference Mission Profile

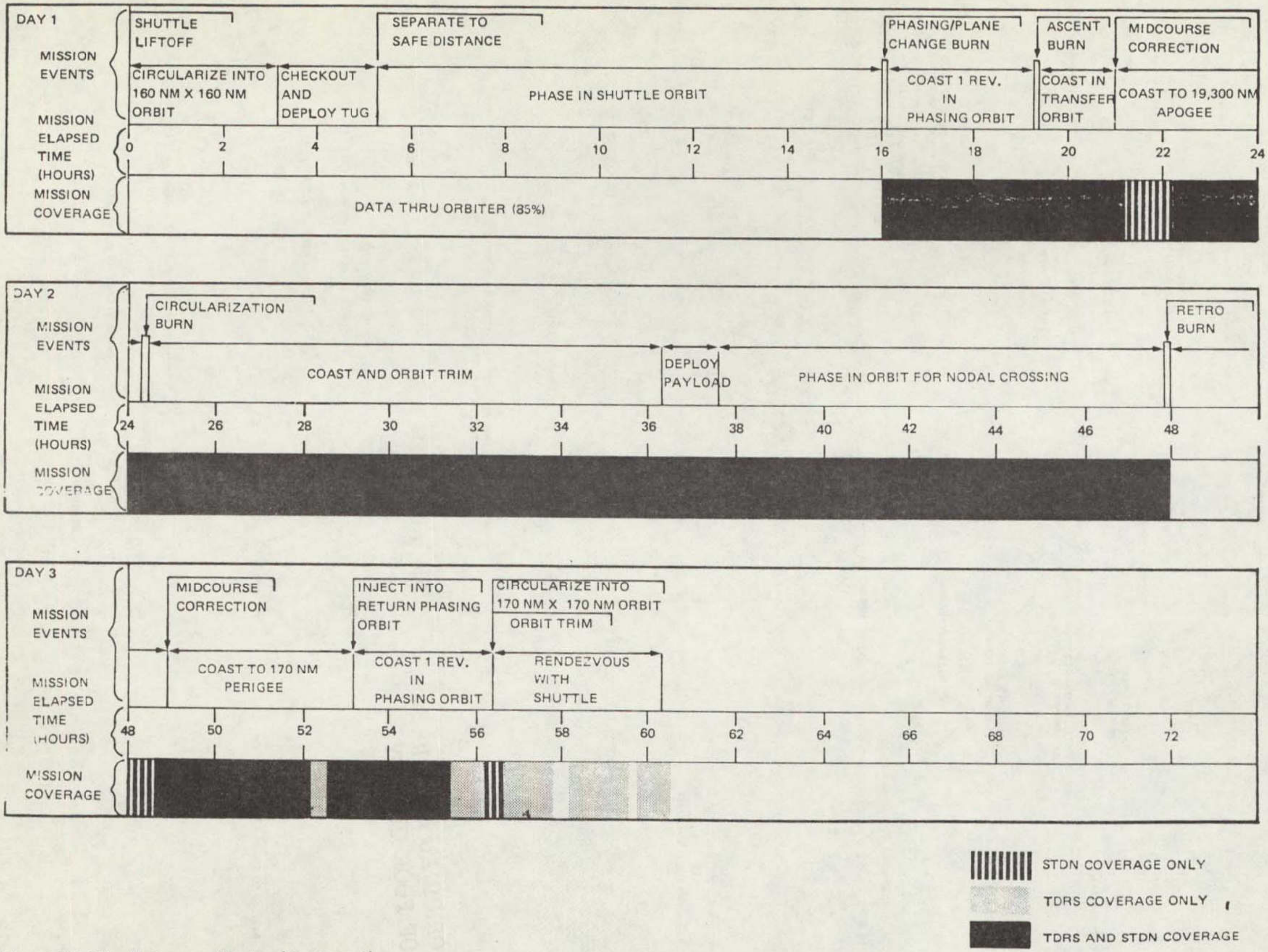

Figure 9.1.2-2. Reference Mission (Outbound)

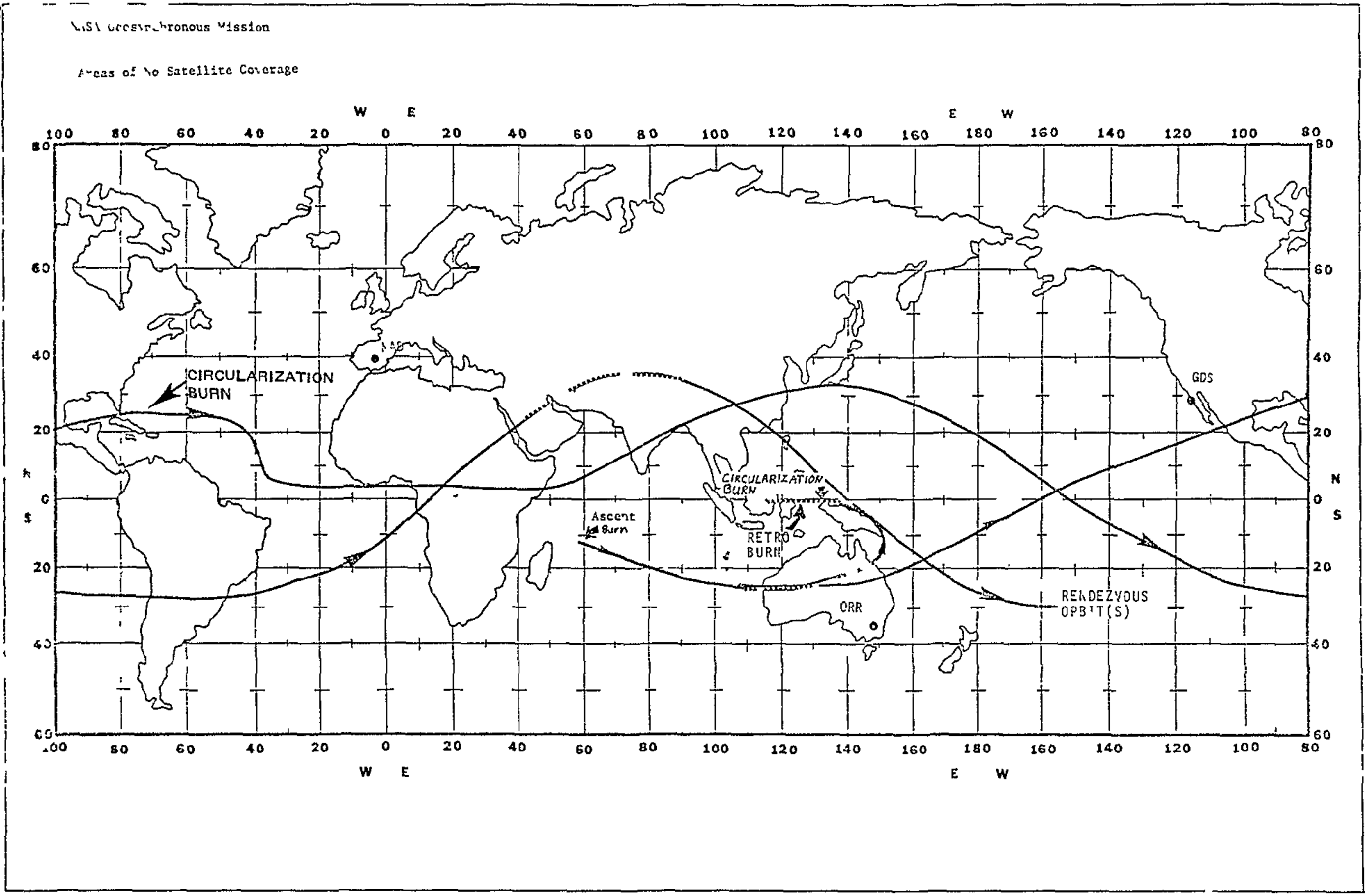

Figure 9 1 3-1 TDRS Only Case

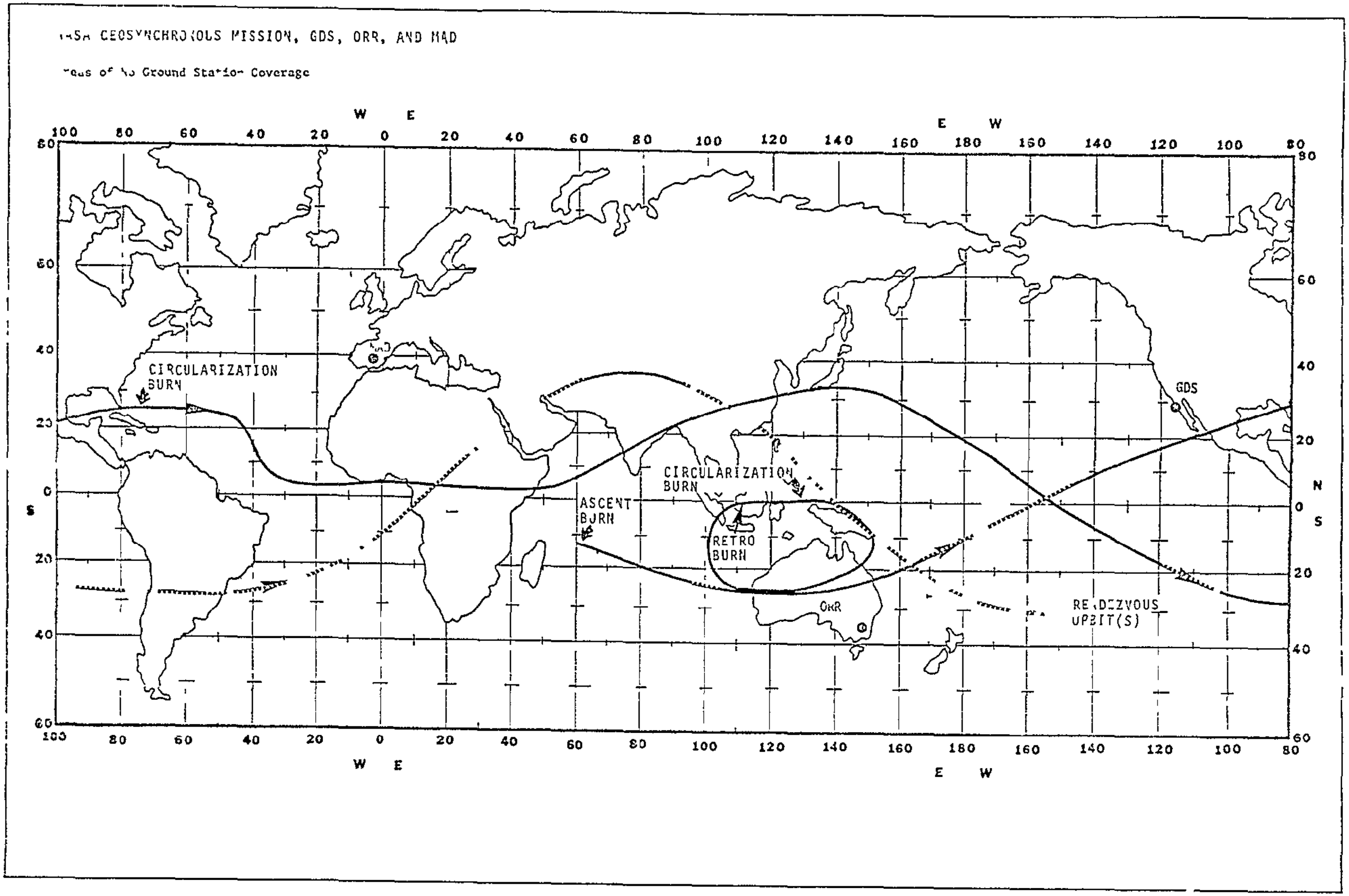

Figure 9 1 3-2. STDN Only Case

9 2 FUNCTIONAL ORGANIZATION

Figure 9 2 0-1 presents an overview of the recommended mission control organization The basic line structure for mission control organization will begin with Mission Director at the apex to whom reports the Orbiter Operations Director, the Tug Operations Director and the Spacecraft Operations Director Coordination between the three involved control agencies will be direct, with the decision authority vested in the Mission Director to resolve conflicting subordinate level requirements. The chart as drawn is relevant to on-orbit operations and does not include the launch operations involvement

The Tug Operations Director is responsible for all aspects of control of the Tug including the facilities maintenance and operations, vehicle systems, flight dynamics, mission planning and special function organization

Reporting to the Tug Operations Director are a Facilities Management group, a Vehicle Systems group, a Flight Dynamics and Mission Planning group devoted to real-time analysis of flight dynamics, real-time retargetting and restructuring of the mission and the preparation of the initial mission plans, and a Special Functions group. The Special Function operation will be Spacecraft particular or experiment related.

9 2.1 Flight Control Organization

The flight control organization begins at the second tier of the mission control organization

During operational periods the Tug Operations Director assumes total authority over all control center functions, including the Facilities Management group. During non-operational times, the Facilities Supervisor directs the support personnel. This report is concerned only with the operational relationships.

The Flight Control Group is responsible for the Tug vehicle and the successful accomplishment of its mission. It is divided into three teams Vehicle Systems, Flight Dynamics, and Special Functions The Facilities Management group operationally reports to the Tug Operations Director but assumes a support, not control activity Personnel manning the positions in the Flight Control Group will be experienced engineering personnel with corresponding design and test responsibility for the Tug system which they monitor and control.

Flight Control personnel are responsible for the real-time control of the Tug. Preparation for these responsibilities requires extensive study and Control Center "on-console" training for each mission Backup personnel must also be equally prepared to assure timely and qualified flight support continuation in contingency situations. Flight controllers must be completely abreast of Tug vehicle systems, the Tug Control Center data display, command system and all details concerning the specific mission being flown.

The basic responsibilities of each team position are listed below

Vehicle Systems Group - The Vehicle Systems Group, reporting to the Vehicle Systems Engineer, monitors real-time Tug data and maintains cognizance of the Tug operational status The team is functionally divided into four areas of vehicle responsibility propulsion, avionics, networks, and communications.

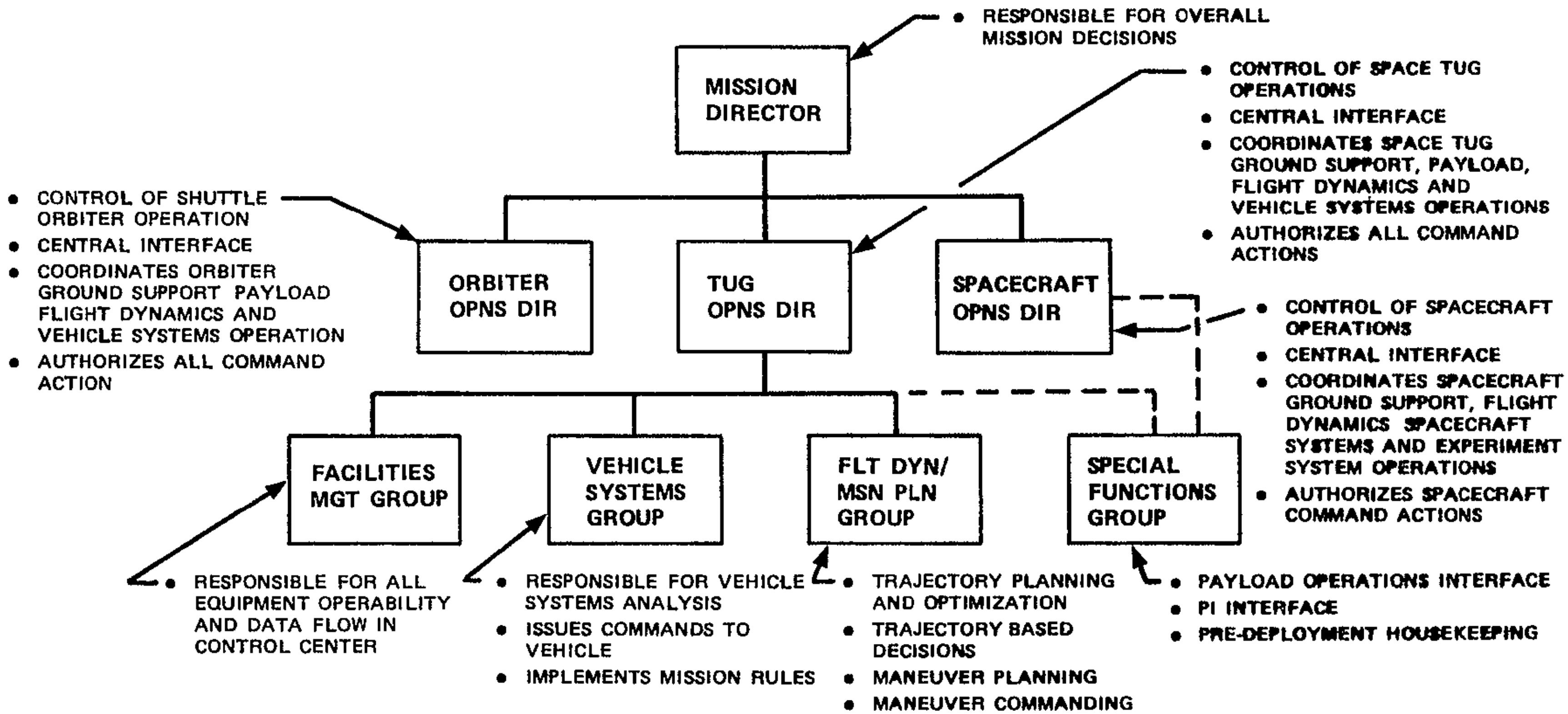

Figure 9.2 0-1. Tug Mission Control Organization

Flight Dynamics/Mission Planning Group - The Flight Dynamics Group, reporting to the Flight Dynamics Engineer, is responsible for Tug vehicle trajectory management This entails the continual comparison of predicted, actual and desired vehicle trajectory and the generation of corrective maneuver seq-ences. Functional divisions of the group are Guidance and Dynamics

Special Functions Group - The Special Functions Group is responsible for monitoring Spacecraft status and most activity during deployment and retrieval operations It is probable that Special Functions Group personnel will vary with the type of Spacecraft being serviced

9 2 2 Facilities Management Organization

The Facilities Management Group is composed of three teams, Data Systems, Maintenance and Operations and Software Support These teams insure and are responsible for control center readiness and operational integrity. These teams report directly to the Facilities Supervisor during mission operations

The Facilities Management Group assists the Flight Control Group with commands, communications, and displays, and maintains and operates all equipment within the facility. This team also provides logistic support for continuous control center operation The Software Support Team operational responsibility requires a continual availability of personnel capable of explaining and/or handling software related problems

9.2 2 1 Organization and Reporting Responsibility

Figure 9 2 2-1 presents the Facilities Management Group organization. The organization is functionally divided into three groups Data Systems, Maintenance and Operations, and Software Support Division is along functional lines, although there is overlap between all three groups.

The leader of the Facilities Management group is known by two titles, used interchangeably, as the Flight Support Director or as the Facilities Supervisor This is indicative of the dual role he has in mission operations. During the real-time period, he reports to the Flight Director and is responsible for overall support to the Flight Control personnel During non-real-time operations, he supervises the maintenance and checkout of the facility equipment In both roles, the Data Systems, Maintenance and Operations and Software Support teams report administratively to him

The Data System Supervisor oversees the activities of the Command, Telemetry and Site Select Technicians.

The computer operators, computer monitors, data flow technician, data processing engineer, voice technician, display technician and TV Technician report directly to the Facilities Supervisor

The Software Support Supervisor heads a team of specialists who are knowledgeable in the mission profile, vehicle systems, executive/control center, and simulation

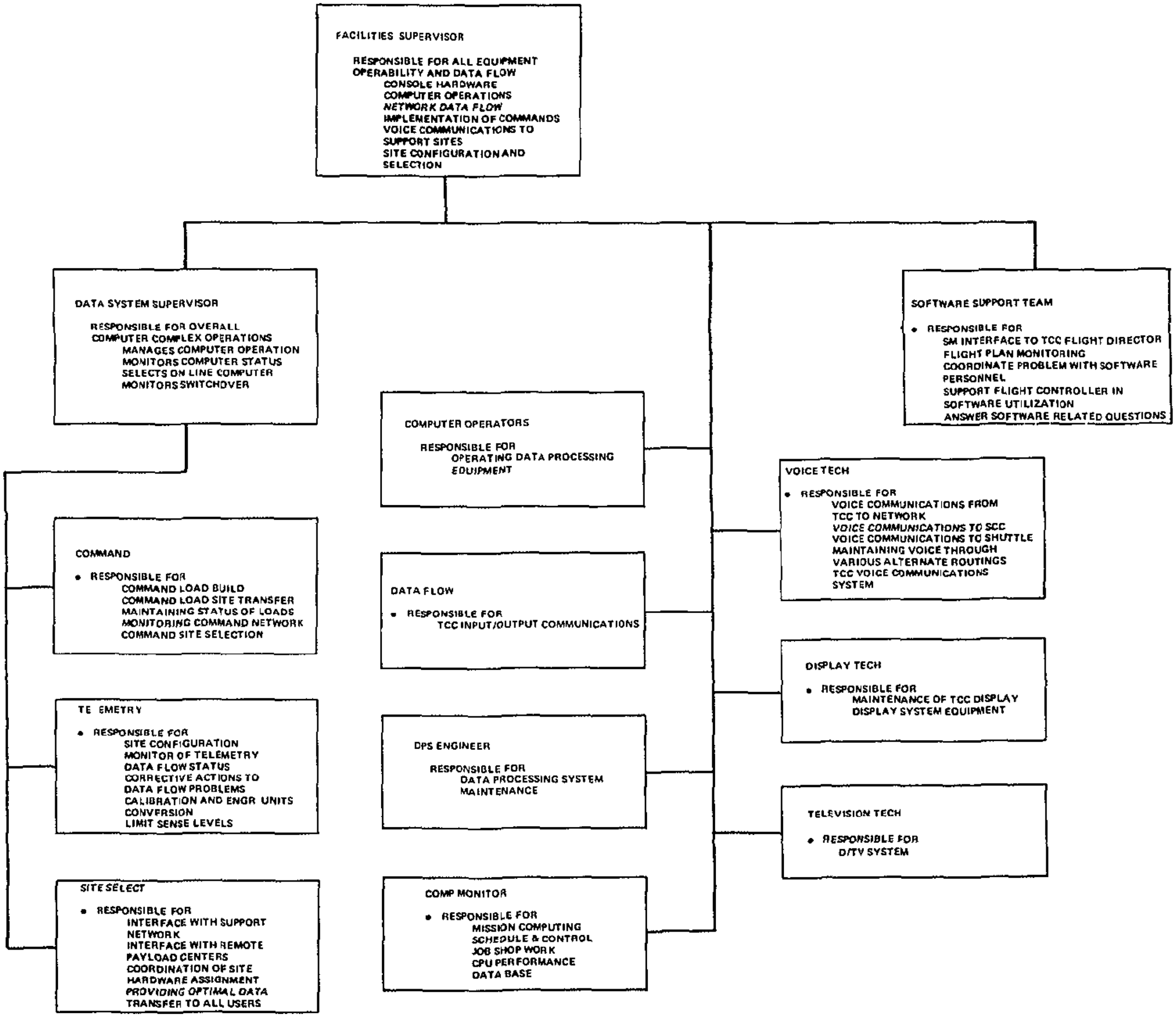

Figure 9 2 2-1 Facilities Management Group Organization

software. These personnel provide expertise during real-time operations to resolve software-related problems, and provide update and mission-peculiar software modifications during non-real-time periods.

9 2 2 2 Data System Support Group Responsibilities

The Data Systems Group is composed of personnel who are actively involved in operating the support systems in real-time. These personnel interface between the flight control personnel and the support equipment, acting as aides and assistants to the flight control personnel. They occupy the same functional relationship to the flight controllers as an aircrew does to a pilot. They are operators, as opposed to maintenance personnel, who interpret data in support of flight controllers

There are three subdivisions under Data Systems telemetry, command and site select.

It is the responsibility of the telemetry technician to monitor telemetry data flow status and to initiate any corrective actions required to maintain telemetry data flow throughput to the flight control consoles. The telemetry technicians will operationally respond to any flight controller's request for telemetry readouts (e.g , bit circuit, calibration data, bit-error rate, etc.), and to the Facilities Supervisor through the Data Systems Supervisor

The command technician is responsible for the construction of command loads in the appropriate format for uplink, the transfer of that load into an uplink data buffer, and monitoring the uplink and verification-of-receipt of the command. The command technician also must track down the sources of errors in the command data flow system, and cause corrective action to be initiated. The command technician responds to any flight controller having a command panel and to the Facilities Supervisor through the Data Systems Supervisor.

The site select technician is responsible for interface between the Tug Control Center and the support network (TDRS and STDN). He will coordinate the selection of the appropriate site to receive telemetry or to uplink commands to the Tug. He is further responsible for checking the operational status at each site and for planning backup or alternate routings for the data connections with the Tug. He is responsible for providing optimum data transfer between the Tug and the Mission Control Center. The site select technician reports to the Data Systems Supervisor, and has no direct contact with the flight controllers

The Data Systems Supervisor is responsible for overall operation of the data systems supporting the flight controllers He manages the computer operation, monitors computer status, selects the on-line CPU and monitors switchover In addition, he has organizational responsibility for the performance of the telemetry technician, command technician and site select technician.

9.2.2.3 Maintenance and Operations Group Responsibilities

The Maintenance and Operations (M&O) Group is composed primarily of equipment maintenance specialists who are responsible for the operability of all Mission Control Center support equipment.

The M&O personnel have no direct interface with the flight controllers in the operational sense, but must be responsive in real-time to requests to fix the equipment In the pre-mission non-operational phases, the M&O technicians must perform periodic maintenance on the equipment and conduct proof-of-performance tests of equipment operation During operational periods, the M&O technicians monitor equipment operation, and are alert to malfunction indications They will notify the Facilities Supervisor when equipment must come off-line for repair, and will coordinate equipment configuration with the Data Systems Technicians

Computer operators operate the data processing equipment associated with real-time flight control operations, and are responsive to requests from the Data System technicians

The computer monitors are responsible for mission computing, scheduling and control of non-mission job-shop work, CPU performance and maintaining of the system data base Computer monitors and computer operators function interactively to maintain the data processing equipment configuration at peak efficiency

The Data Processing System Engineer is responsible for the maintenance of the data system CPU and peripherals This function is best performed by a maintenance contractor which will provide a DPS engineer to NASA who will respond as a member of the Flight Support Team This function requires highly specialized skills and training normally available only from the Data Processing System manufacturer. During operational periods, the DPS engineer reports functionally to the Facilities Supervisor During non-mission periods, he executes the requirements of a Data System Maintenance Contract

The Data Flow Technician is responsible for all equipment interfacing between the data system and the outside world This will include all MODEMS and line termination equipment which interface with the network During operational periods, he will monitor the equipment performance and select the terminals having best operational characteristics During non-operational periods, he will perform periodic maintenance and conduct proof-of-performance tests on the equipment

The Display Technician is responsible for maintaining the equipment which interfaces with the flight control personnel, consoles, console displays and group displays During operational periods he monitors the operation of the equipment and stands-by to execute immediate replacement or repair of the equipment During non-operational periods, he will perform periodic maintenance and conduct proof-of-performance tests The Display Technician directly interfaces with and is responsive to direction from the flight control personnel in real-time.

The Voice Technician is responsible for all voice communications internal to the control center, and for all voice communication with external operational entities He is the primary interface with the common commercial carriers

which provide communications service to the Mission Control Center The Voice Technician maintains all communications loops in operational configuration

9 2.2 4 Software Support Group Responsibilities

The software support team will consist of high-level software personnel who are functionally familiar with the overall software and its capabilities Because the software is the critical element in achieving the Mission objectives, the software support team must be able to respond rapidly to software-related questions and actively participate with flight support group team members in the effective utilization of the software capabilities.

The software support supervisor will be responsible for the continuous software support and development activities after intial delivery of the software system He will provide the interfaces with NASA and contractor personnel for all software-related functions To provide the necessary interfaces, he will have a staff of software/hardware systems personnel to perform the following functions

- Software Reviews
- Configuration Control
- Software Audits
- Continuing Customer Interfaces
- Project Status Reporting (Costs and Schedules)
- Document Control

A software development section will be responsible for the updating of the software to support changing requirements. Previous space programs of long duration, such as Apollo, have shown that the software within the control center will continue to evolve throughout the lifetime of the program. The RTCC software, for instance, grew in size by a factor of 50 percent over the lifetime of the Apollo program This growth was distributed among all the elements of the software

To address the requirements for continual software change, the software development activity has been organized according to the functional software requirement areas

- Mission Profile
- Vehicle Systems
- Executive/Control Center Support
- Simulation and Training

Mission Profile - The mission profile group will be responsible for maintenance and support ot the software which addresses the mission profile function These software elements are

- Orbit Trajectory Determination
- Orbit Trajectory Computations
- Mission Planning

Vehicle Systems - The vehicle systems group will be responsible for maintenance and support of the uplink and downlink processing software.

Executive/Control Center Support - The executive/control center support areas of the control center software will be highly volatile because of the changing display requirements and response time changes as a result of mission changes and vehicle changes. This support group will maintain and support all changes to these areas

Simulation and Training - The simulation and training software group will be responsible for modifications of the simulation software system which reflect changes in mission profiles and vehicle configuration In addition, this group will conduct training sessions in software capabilities for the flight support group and will support the use of the simulation system during ground controller training

The central computers of the control center will be utilized for real-time mission support, training of flight support personnel, software development, and normal jobshop operations It is assumed that for cost effectiveness, the computer operations will be three shift/day, seven day a week operations

9 2 3 Recommended Manning Level

The following paragraphs describe the recommended manning levels for Tug operations Major divisions in manning are (1) Facilities Maintenance or Flight Support Staff and (2) Flight Control Staff

9 2 3 1 Facilities Maintenance or Flight Support Staff

There are 33 personnel required to staff the Facilities Maintenance or Flight Support organization on a continuing basis Table 9 2 3-1 presents a breakdown of the staff requirements

The size of the staff is established by the real-time support requirements However, the staff, during non-mission and non-training periods, is to be utilized to perform mission preparations and maintenance jobs This multiplexing of personnel is cost-effective in that it spreads the productive work load of the permanently assigned personnel more evenly across the operational periods

Table 9.2 3-1. Flight Support Staff Requirements

POSITION	MAX MANNING	NO. OF CONSOLES	SHIFT DENSITY	TOTAL REQ
FLIGHT SUPPORT GROUP				
FLIGHT SUPPORT DIRECTOR	1	1	2	2
DATA SYSTEM SUPERVISOR	1	1	2	2
COMMAND	1	0	2	2
TELEMETRY	1	1	2	2
SITE SELECT	1	0	2	2
TV TECH	1	0	2	2
DATA FLOW	1	1	2	2
DPS ENGINEER	1	0	2	2
VOICE TECH	1	0	2	2
DISPLAY TECH	1	0	2	2
COMPUTER SYSTEM MONITORS	2	1	2	4
COMPUTER OPERATIONS	3	0	2	6
COMPUTER SUPPORT	3	0	1	3
TOTALS	18	5	-	33

9 2 3 2 Flight Control Staff

There is a specific minimum staff required to control the Tug vehicle during mission operational periods For the Tug program, that staff requirement is 30 flight control engineers The flight control organization is a required sustaining engineering staff which may be utilized during non-mission periods in performing preparation tasks, such as training, scheduling, and interface type operations As with the flight support staff, the spreading of effort across the period of operations is a cost-effective utilization of the flight control staff Table 9 2 3-2 presents the flight control staff requirements

Table 9.2 3-2 Flight Control Staff Requirements

POSITION	MAX MANNING	NUM OF CONSOLES	SHIFT DENSITY	TOTAL REQ.
FLIGHT CONTROL GROUP				
TUG OPERATIONS DIRECTOR	1	1	2	2
VEHICLE SYSTEMS ENGINEER	1	1	2	2
PROPULSION	1	1	2	2
STAGE SYSTEMS	1	1	2	2
CONSUMABLES	1	0	2	2
NETWORKS	1	1	2	2
COMMUNICATIONS	1	0	2	2
AVIONICS	1	1	2	2
GUID AND NAV	1	0	2	2
SEQUENCE	1	0	2	2
GUIDANCE	1	1	2	2
DYNAMICS	1	1	2	2
TV/DOCKING	1	1	2	2
FLIGHT DYNAMICS OFFICER	1	1	2	2
SPECIAL FUNCTIONS	1	1	2	2
TOTALS	15	11	-	30

9.2 3.3 Derivation of Manning Requirements

Before arriving at an estimate of recurring cost, it was necessary to investigate the impact of simultaneous missions and mission module overlaps on the level of support required

To accomplish this impact analysis, IBM developed a mission density factor program This program creates a launch schedule and mission module timing schedule from which the overlap of missions and mission modules is developed. At the same time, gaps in the schedule are identified which can be used for training and simulation tasks

Outputs from the mission density factor program drive the following dependent cost relationships.

Computer Support Personnel - Establishes the hours the computer is committed

Sustaining Flight Control	- Establishes the number of shifts required and the number of personnel required
Flight Support Personnel	- Establishes the number of shifts required and the number of personnel required.
Flight Control Consoles	- Establishes the number of consoles required by type
Network Rental	- Establishes the number of hours required in one year of TV, Telemetry, Command and Tracking Service

9 2 3 4 Sustaining Support Personnel

The mission density function establishes the computer commit hours per year, which then is converted to equivalent men required to provide computer support

The mission density function also establishes the shift density factor for flight support personnel The level of effort established for flight support is constant No provision has been made to assign other duties to the flight support staff

The mission density function provides a shift density factor and console multiplier which are combined to create a manpower requirement estimate The level of effort established for flight control support is constant No provision has been made to assign other duties to the flight control staff

9 2 3 5 Ground Software Maintenance

Since software problems will be identified throughout the entire software module set, it is necessary to provide resident personnel familiar with every area The number of personnel required is dependent upon the size, complexity, criticality and level of mission-to-mission changes for the program Twenty-three programmers have been estimated as required to perform the ground software maintenance

9 2 3.6 Flight Software Maintenance

Flight software maintenance is similar to ground software maintenance in concept It is necessary to maintain a staff of personnel who are familiar with each of the four basic programs, and to maintain capability to define, code and verify the flight programs Twenty-one programmers are required to supply mission modifications, coding and verification for the four baseline programs

9 3 FLIGHT CONTROL FUNCTIONAL REQUIREMENTS

The following paragraphs define the nominal and contingency functions of the Flight Control Organization.

9 3.1 Vehicle Systems Group

The vehicle systems group is required for Tug mission control. The vehicle system group is formed of a leader and four subordinate organizations. The leader, the Vehicle System Engineer, is responsible for all vehicle systems, and will coordinate the analysis of vehicle systems and issues all commands to the vehicle which are directly related to hardware functions, as opposed to trajectory shaping functions. The vehicle systems engineer is a primary consultant and recommends implementation of mission rules based upon the state of affairs at a given time during the mission

Reporting to the Vehicle System Engineer is the propulsion group, which is responsible for the main propulsion system, the attitude control propulsion system, pneumatics, propellant tank management, main engine performance and main engine support devices, maintaining knowledge of consumables utilization, structures and thermal control considerations.

The second major division under the vehicle systems group is the avionics support team The avionics support team is responsible for the analysis of all hardware relevant to the guidance, navigation and control system and the attitude and thrust vector control systems Two suborganizations beneath the avionics organization are the Guidance and Navigation Engineer and the Sequential Systems Engineer with the primary division between those two being between sensor hardware and computational hardware analysis

The third breakdown beneath the vehicle system engineer is the network responsibility All functions relevant to the electrical power capability, battery charge, fuel cell operation and electrical loads are the responsibility of the Networks System Engineer

The fourth subdivision is the Communications System Engineer. This engineer is responsible for maintaining cognizance of the status of the communications systems for uplink, downlink, and tracking functions Additionally, he is responsible for the generation of commands and the coordination of uplink requirements with the network He maintains cognizance over the signal conditioning, multiplexers, transducers, and RF components of the telemetry systems.

Figure 9 3 1-1 presents the vehicle systems group organization

9.3.2 Flight Dynamics and Mission Planning Group

The flight dynamics and mission planning organization is concerned, in the pre-mission period, with the structure and generation of the optimum mission trajectory based upon the Payload, Orbiter and Tug operational constraints In real-time the flight dynamics organization is responsible for trajectory planning and shaping, all decisions based upon trajectory considerations, planning of maneuvers, commanding maneuvers, plus maintaining knowledge of the Orbiter, Payload and Space Tug ephemerides.

Figure 9.3.2-1 presents the Flight Dynamics and Mission Planning Organization There are three basic subdivisions beneath the flight dynamics organization Guidance, Dynamics and Television/Docking The Guidance engineer is responsible for monitoring vehicle performance during guidance phases, the analysis of drift in references, the optimization of corrective maneuver, the recommendation

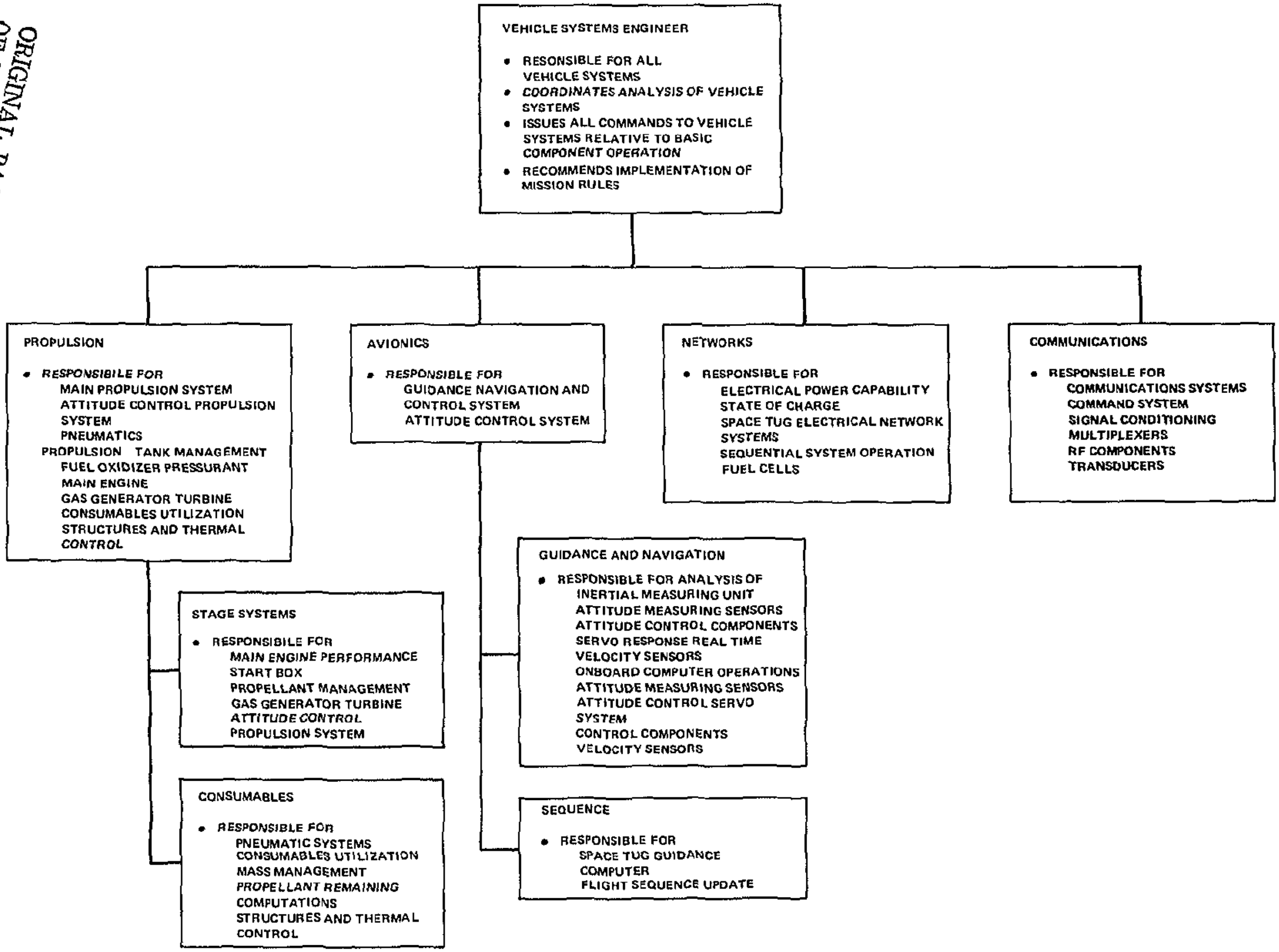

Figure 9 3 1-1 Vehicle Systems Group Organization

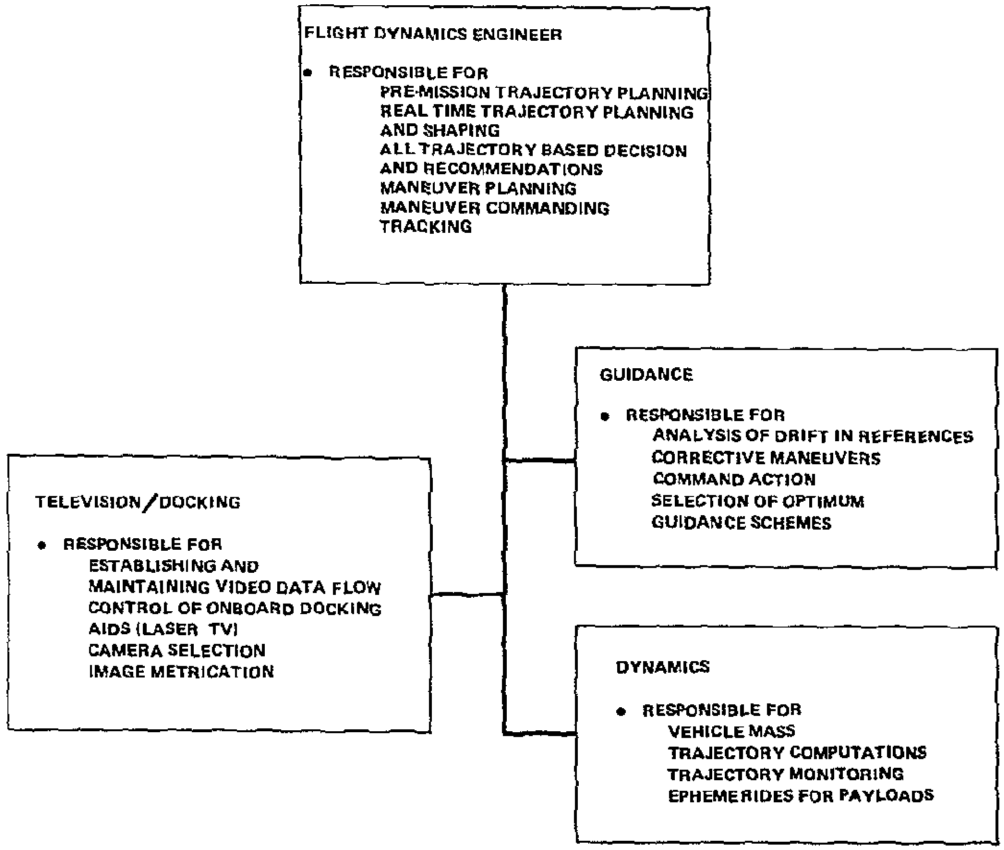

Figure 9 3 2-1. Flight Dynamics and Mission Planning Organization

of command action to accomplish those maneuvers, and the selection of the optimum guidance scheme for a particular mission maneuver. The Dynamics engineer is responsible for maintaining knowledge of vehicle mass characteristics, the monitoring of the trajectory, and the overseeing of the trajectory computations which result in the ephemeris tables for the Space Tug, Payloads and Orbiter. The Television/Docking engineer is responsible for establishing and maintaining video data flow and control of the on-board docking aids, the selection of cameras as necessary to support the docking operation, and the mensuration of image data. He will also be responsible for all near-in terminal docking phases and will work closely with the Spacecraft Operations Center during the docking operation

9 3 3 Special Functions Group

Provision has been made for a "Special Function" group to be incorporated into the basic Tug operations organization in order to accommodate experiment packages or unique Spacecraft missions that may require additional specialists for specific functions Figure 9 3 3-1 shows the Special Functions group organization

The one permanent member of the Special Function group is the Special Functions engineer who will be responsible for all payload operations from predeployment monitoring and housekeeping through interface with the principal investigator.

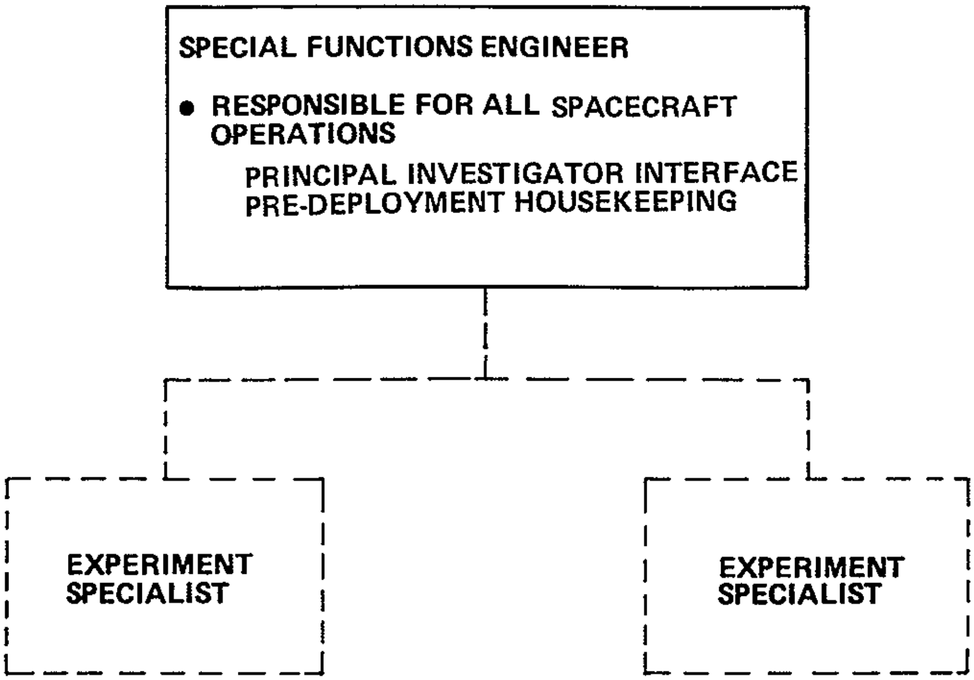

Figure 9 3 3-1. Special Functions Group

9 3 4 Facilities Management Group

The Facilities Management Group (reference Figure 9.2 2-1) is responsible for providing the necessary data, command and network configuration coordination required to support the Tug mission All scheduling interfaces with the network operations will be conducted by this team Additionally, all hardware and software maintenance required in the Tug control center will be provided by the facility management group

There are three basic organizational entities reporting to the facilities management supervisor Those organizations are the data system subgroup, the maintenance and operations subgroup and the software support team

The data system supervisor has three groups reporting to him, a command group, a telemetry group, and a site select group The data system supervisor collectively has responsibility for overall operation of the computer complex and is responsible for telemetry, tracking and command interface with the support network

The maintenance and operations organization is responsible for the operability of the data processing and display equipment, communications equipment, the overall facility capabilities and the mission support logistics The group has seven specialists computer operators, a data flow specialist, a data processing system maintenance engineer, a computer monitor, television technician, display technician, and voice technician

The software support team is responsible for maintaining the support software in an operable condition, coordinating the problems with the flight

director as required and for answering of all software related questions, including operational utilization of the software by the flight controllers

9 3 5 Ground Software Support Group

It is reasonable to assume that there will be changes from mission to mission in the Tug Control Center software. To effect these changes, a Software Support Group will be required. This organization is depicted in Figure 9 3 5-1 and will be discussed in the following paragraphs.

9 3 5 1 Project Manager/Project Office

The software project manager will be responsible for the continuous software support and development activities after initial delivery of the software system. He will provide the interfaces with NASA and other contractor personnel within the control center for all control center software-related functions. To provide the necessary interfaces, he will have a project office staff of five software/hardware systems personnel to perform the following functions·

- Software Review
- Configuration Control
- Software Audits
- Continuing Customer Interfaces
- Project Status Reporting (Costs and Schedules)
- Document Control

9 3 5.2 Software Development Section

The software development section will be responsible for the continual updating of the software to support changing requirements. Previous space programs of long duration, such as Apollo, have shown that the software within the control center will continue to evolve throughout the lifetime of the program. The RTCC software, for instance, grew in size by a factor of 50 percent over the lifetime of the Apollo program. This growth was distributed among all the elements of the software.

To address the requirements for continual software change, the software development activity has been organized according to the functional software requirement areas As shown in Figure 9.3.5-1, these areas are

- Mission Profile
- Vehicle Systems
- Executive/Control Center Support
- Simulation and Training

9.3 5.3 Mission Profile

The mission profile area will be responsible for maintenance and support of the software which addresses the mission profile function. These software elements are

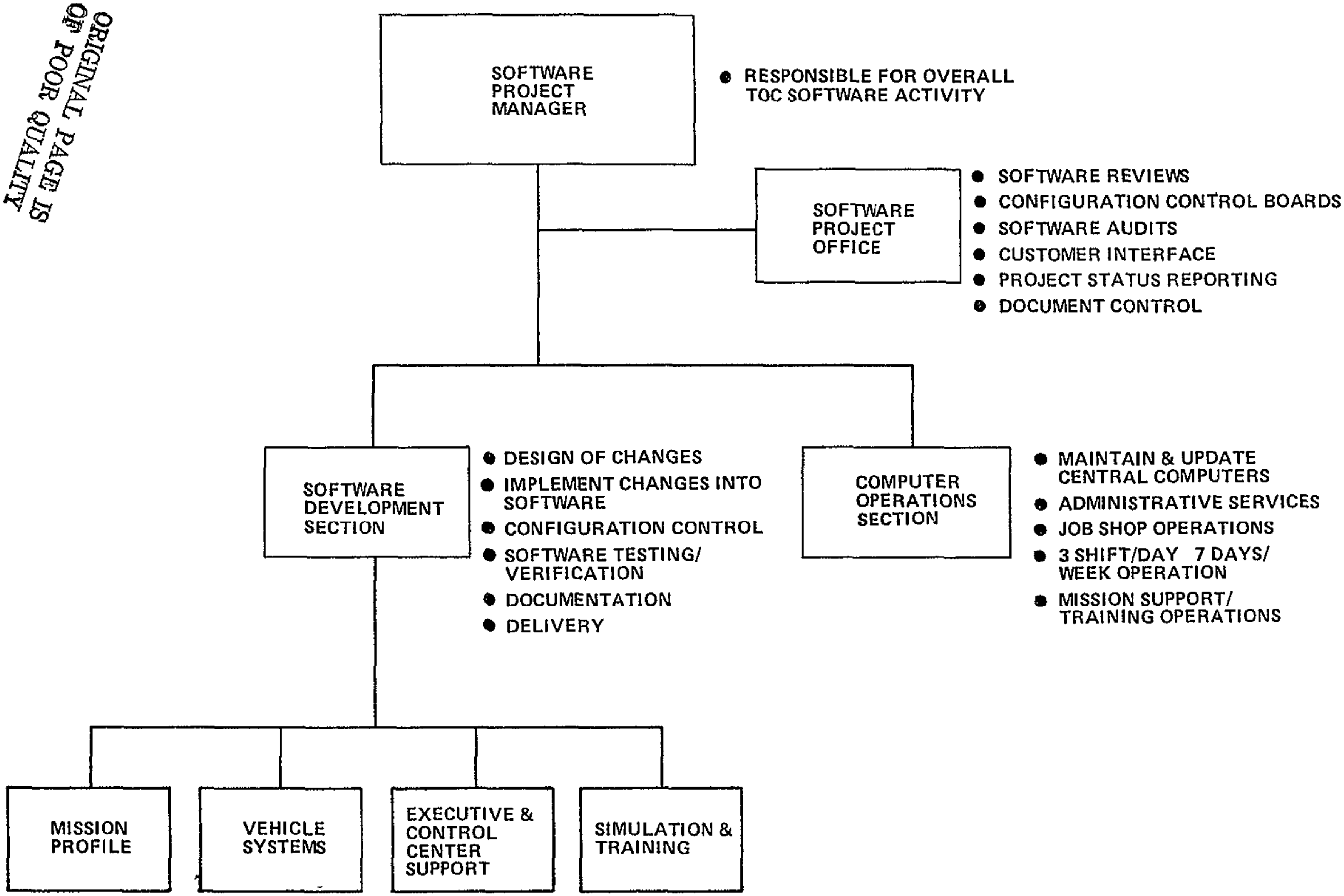

Figure 9 3 5-1 Software Support Group

- Orbit Trajectory Determination
- Orbit Trajectory Computations
- Mission Planning
- Docking

9.3.5.4 Vehicle Systems

The vehicle systems group will be responsible for maintenance and support of the uplink and downlink processing software of the Tug Control Center.

9 3 5.5 Executive/Control Center Support

The executive/control center support areas of the software will be highly volatile because of the changing display requirements and response time changes as a result of mission changes and vehicle changes. This support group will maintain and support all changes to these areas

9 3 5.6 Simulation and Training

The simulation and training software group will be responsible for modifications of the simulation software system which reflect changes in mission profiles and Tug vehicle configuration. In addition, this group will conduct training sessions in software capabilities for the flight support group and will support the use of the simulation system during flight controller training.

9.3.5.7 Computer Operations Section

The central computers of the control center will be utilized for real-time mission support, training of flight support personnel, software development, and normal jobshop operations It is assumed that for cost effectiveness, the computer operations will be three shift/day, seven day a week operations, and is staffed accordingly. Included within this section are keypunch services, tape librarians, administration personnel, management personnel, customer engineers, as well as the computer operations personnel

9 4 ORBITER CREW FUNCTIONAL REQUIREMENTS

Since the Space Tug is recommended to be designed as a highly autonomous vehicle, there is minimal interface with the Orbiter crew What interaction exists, is, for the most part, monitoring of caution and warning parameters and backup to critical sequences in the event of contingency situations

9.5 OPERATIONS SUPPORT REQUIREMENTS

This section summarizes the hardware, software, and data system required to support real-time Tug operations

9.5 1 Airborne Operations Support Hardware

The Tug Avionics System has the dominant impact upon mission operations. The implementation of control decisions can be shifted between the onboard avionics and the ground based electronics. This shift is a function of the level of autonomy to which the Tug is designed.

In general, the shift of control authority to the onboard system is desirable, since the implementation of any control on the ground carries with it a heavy overhead for transfer of data from the vehicle relative to its physical conditions to a ground based information assimilator This overhead (tracking, telemetry, command, etc) contributes nothing to the decision processes

Figure 9 5 1-1 presents the Space Tug avionics system, which houses the airborne operations support hardware

The basic avionics configuration provides a centralized digital computer with a data bus/DIU system for data acquisition and distribution The configuration shown, along with the appropriate software, provides a high capability vehicle capable of autonomous operation (except for docking, which is ground-aided) The avionic system is basically dual redundant The following is a brief description of each subsystem

Data Management - The DMS provides a fault tolerant memory configuration in conjunction with dual CPU's and IOP's to provide the storage, processing and input/output operations for the Tug vehicle The CIU, data bus and 4 DIU's provides command and data routing and the gathering and formatting of telemetry data The tape recorder records maintenance data

GN&C - The laser gyro IMU, in conjunction with the DMS, provides the basic inertial reference system for the Tug The interfermetric landmark tracker (ILT) provides onboard state vector update capability and the star tracker/ sun sensor combination provides autonomous attitude update capability The laser rate gyros aid flight control operations

Rendezvous and Docking - The scanning laser radar provides autonomous rendezvous capability, while the man-in-the-loop LLLTV system provides for Spacecraft docking and visual inspection of Spacecraft

Communications - A phased antenna system with dual redundant decoders and transponder provide omnidirectional and directional capability for Tug telemetry, tracking and command external interface

Electrical Power - The Tug power is generated by redundant fuel cells with an emergency backup battery

9 5 2 Ground Operations Support Hardware

The hardware analysis is divided into two parts, i e , that utilized by the mission support staff (consoles, communication panels, etc) and that required for the Tug Control Center Data System

9 5 2.1 Data System

The data system in the Tug Control Center is the system by which incoming, outgoing, and intercenter intelligence is processed, routed and managed. The data system is depicted in Figure 9 5 2-1. The computer is the central element of the system, and because of its significance, it has been addressed separately. The remaining elements of the system are discussed in the following paragraphs

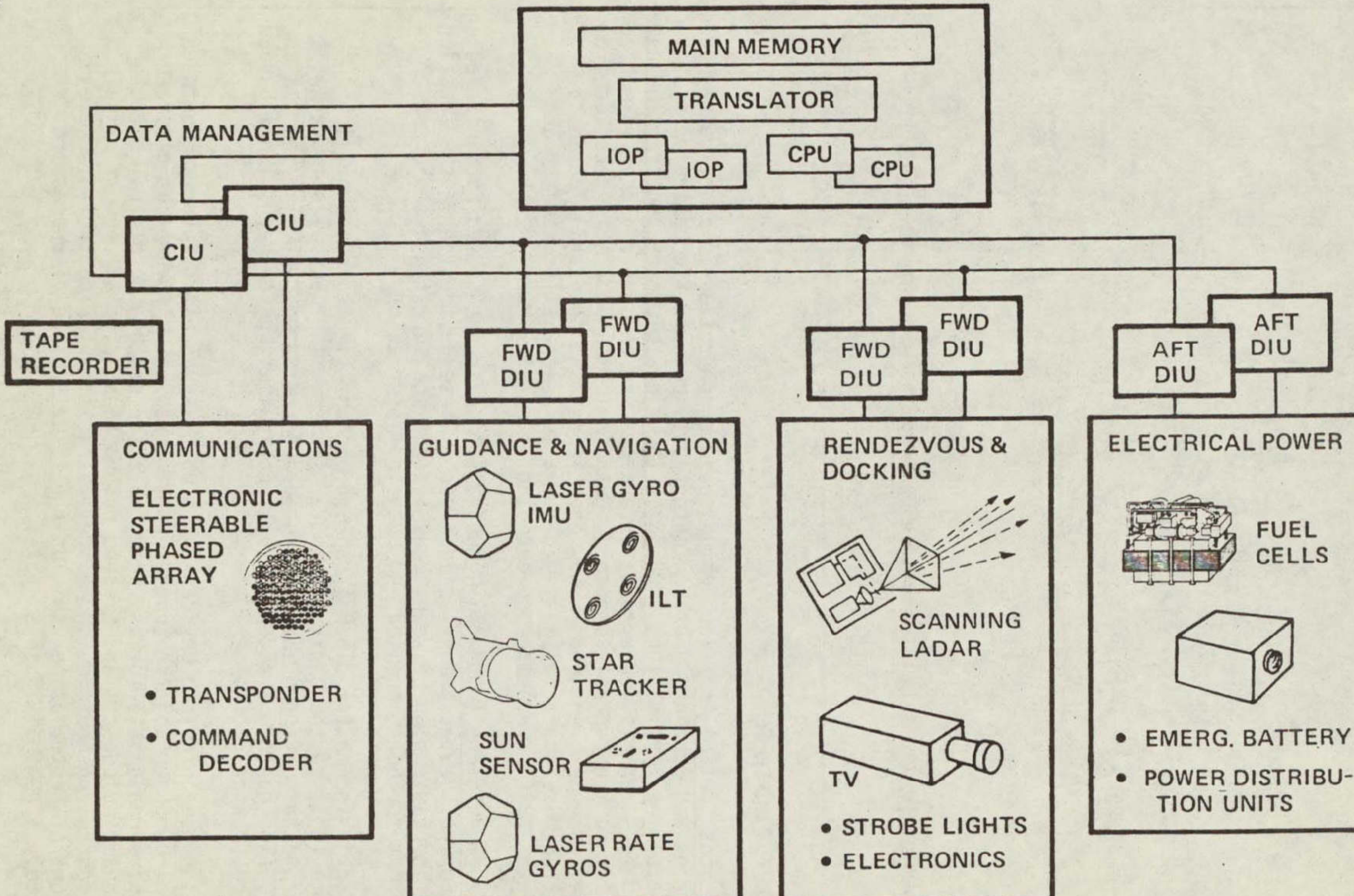

Figure 9.5.1-1. Space Tug Avionics System

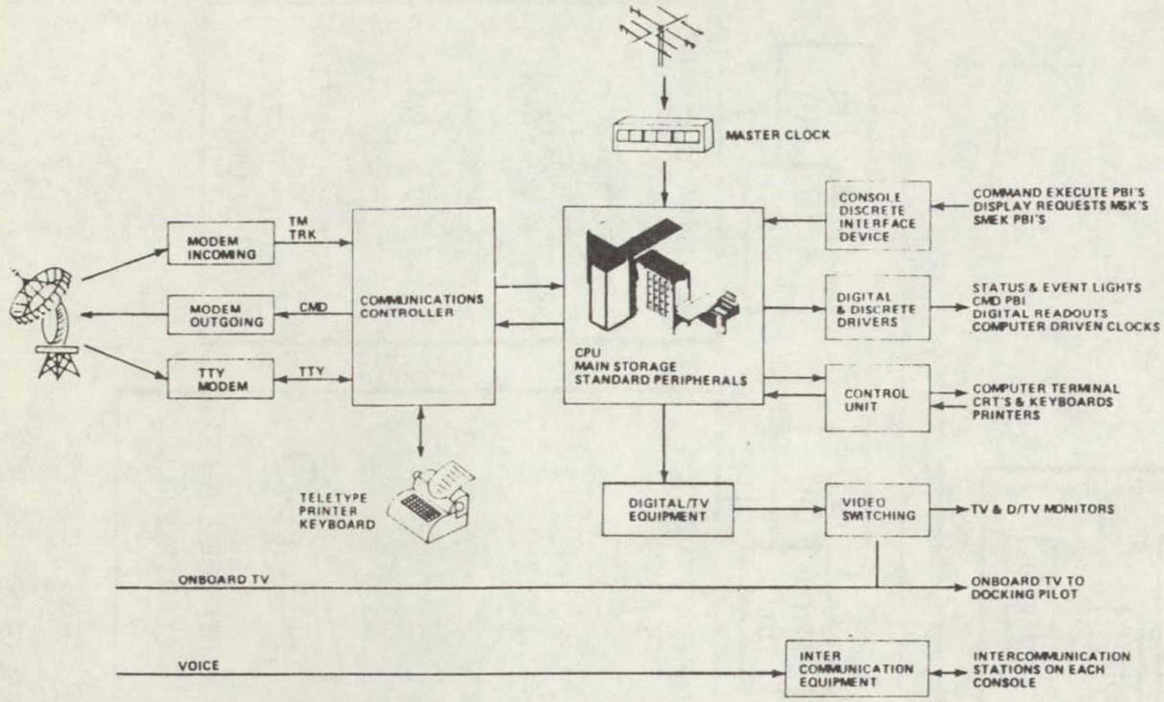

Figure 9.5.2-1. TOC Data System

Communications Controller - The communications controller is a device required for buffering and routing input and output data between the central computer and the data line terminations (MODEMS). Incoming telemetry and tracking data is checked for transmission errors, error encoding removed and then formatted for transfer to the central computer. Outgoing command data is received from the central computer, encoded into proper format and then transferred to outgoing transmission facilities. The unit is essentially a switch and storage facility for incoming and outgoing data.

Modulator/Demodulators (MODEM's) - MODEMS are devices required for interfacing with Tug Control Center transmission lines. These devices serve the function of modulation conversion between transmission line format and the computer system format for both incoming and outgoing information.

Master Clock - The master clock is an independent time source supplying master time (GMT) to the central computer system. The central computer will then generate the differential times needed for mission control. The master clock will also contain a receiver for synchronization to the National Bureau of Standards master clock.

Console Discrete Interface Device - This unit serves as an interface between the central computer and the support staff consoles. It compiles discrete and digital signals into formats acceptable for use by the central computer. These signals include command execute pushbuttons, display request signals, computer control pushbuttons and miscellaneous computer control discretes. For Tug Control Center usage, this unit will be capable of processing approximately 1200 individual signals.

Digital and Discrete Drivers - The digital and discrete drivers are interface devices between the central computer and console displays which receive digital and discrete word outputs, de-multiplex these words and then drive individual lamps, readouts, etc These drivers are required for all status and event lites, command pushbutton indication lites, digital readouts, and clock readouts For Control Center usage, the system will handle approximately 2000 individual discretes

Digital TV Equipment - Digital TV Equipment (DTE) is required to convert computer generated display data into video and video associated signals compatible with the support staff console TV monitors The DTE combines static background format data stored by the computer with the dynamic data being processed by the computer in real-time and formats the information for display on the TV monitors Display refresh is performed by the DTE Only updated information, that is, information which has changed since the last refresh cycle, is transferred from the computer to the DTE

Video Switching Equipment - The Video Switching Equipment distributes Digital TV data from the computer to individual console TV monitors. Live and recorded Tug TV will also be routed through the video switch to the support staff consoles as required during the mission. Scan conversion provisions will be provided to make commercial, Tug video and display systems compatible.

Computer Terminal Equipment - During a Tug mission, some of the communications between the support staff (particularly flight controllers) and the central computer can be conducted most efficiently using standard terminal equipment.

These terminals consist of a Manual Entry Device (MED) and a CRT display. Nominally, one display control unit (interfacing unit to the computer) will be required for each combination of six of these terminals

Teletype Printer/Keyboard (TTY) - A TTY Printer/Keyboard will be required in the Control Center for general administrative message receipt and generation.

Communication Equipment - This equipment provides voice communications throughout the Control Center and interfaces with external commercial/common carrier lines For Tug operation, a central switchboard will be required to provide the following

- 30 internal loops
- 15 external connections
- 10 PABX stations

The PABX will be configured such that no more than five positions will have the same rotary number.

Computer Peripheral Equipment - The central computer will require standard peripheral equipment in addition to the Central Processor Unit (CPU) and memory Standard peripheral devices such as tape drives, disc storage, channel control, line printer, card reader and interface adapters will be configured for Control Center support.

9 5 2 2 Support Staff Hardware Requirements

The mission support analysis discussed in this document delineates various positions and their responsibilities to support a Tug mission To effect the support from these personnel will require a means whereby information can be made available to them for decision and action

Dissemination of this information is achieved by displaying the information to the support staff in the form of TV displays, discrete light indicators, meters, etc For convenience, pertinent indicators and computer driven TV displays are lodged in operator consoles according to the requirements of that position

Table 9 5 2-1 summarizes the equipment necessary for each position to perform the required duties assigned to it

9 5 3 <u>Ground Operations Support Software</u>

The Tug Control Center Software, which resides in the central computer, provides centralized processing of telemetry inputs received from the ground network and performs other complex mathematical and logical functions in support of flight controllers In addition, software will exist to (1) provide a normal computer center jobshop environment when not supporting the real-time Tug mission, and (2) to provide simulation capability in support of software development, ground controller training, and procedure verification The principal emphasis within this discussion of the Tug Control Center Software will be on the Tug mission support areas of real-time processing and simulation activity prior to actual flight

The mission support software consists of several interdependent application subsystems operating in real-time to satisfy the overall support requirements of the control center The interrelationships of the control center hardware and software required to satisfy the support role are shown in Figure 9 5.3-1

In addition to defining the Control Center functional software specification, the establishment of the overall size of the software is required. This sizing information will be later used in costing of software development and in establishing the specific central computer size required to support the Control Center. Because of costing differences, the software size will be presented in the form of computer words for instruction utilization and those used for data allocation The differentiation between data and instruction definitions is shown in Table 9 5 3-1 With each of the paragraphs which discuss the Control Center software requirements, the corresponding size information will be provided

The Control Center mission support software has been subdivided into four major functional areas for discussion in this report These areas are (1) vehicle systems, (2) mission profile, (3) control, and (4) simulation. These four subdivisions have been further divided, as shown in Figure 9 5.3-2, and will be discussed in the order shown.

Table 9 5.2-1. Support Staff and Flight Control Staff Equipment Allocation

POSITION	MAXIMUM MANNING	CONSOLES	COMM. PANEL	TV MONITORS	EVENT MODULES	SUMMARY MESSAGE KEYBOARD	COMMAND PANEL	TV DISPLAY CONTROL
FLIGHT DIRECTOR	1	1	1	2	4	1		1
VEHICLE SYSTEMS ENGINEER	1	1	1	2	4	1	1	1
PROPULSION	1	½	1	1	2	1	1	1
STAGE SYSTEMS	1	½	1	1	2			1
SEQUENCE	1	½	1	1	2	1		
CONSUMABLES	1	½	1	1	2			1
NETWORKS	1	½	1	1	2	1		
COMMUNICATIONS	1	½	1	1	2	1	1	
AVIONICS	1	½	1	1	2	1		1
GUIDANCE & NAVIGATION	1	½	1	1	2		1	
FLIGHT DYNAMICS OFFICER	1	1	1	2	4	1	1	1
GUIDANCE	1	1	2	2	4	1		1
DYNAMICS	1	1	2	2	4	1		1
SPECIAL FUNCTIONS	1	1	1	2	4	1	1	1
TELEVISION/DOCKING	1	1	1	1	2	1		1
FLIGHT SUPPORT DIRECTOR	1	1	1	2	4	1	1	1
DATA SYSTEM SUPERVISOR	1	½	1	1	2	1		1
COMMAND	1	½	1	1	2		1	
TELEMETRY	1	½	1	1	2	1		1
SITE SELECT	1	½	1	1	2			
COMPUTER SYSTEM MONITORS	2	1½	3	3	6	1		1
DATA FLOW	1	½	1	1	2	1		1
DPS ENGINEER	1							
VOICE TECH	1							
DISPLAY TECH	1							
TELEVISION TECH	1							
COMPUTER OPERATIONS	3							
SOFTWARE SUPPORT TEAM	3							
TOTAL	33	16	26	31	62	17	8	16

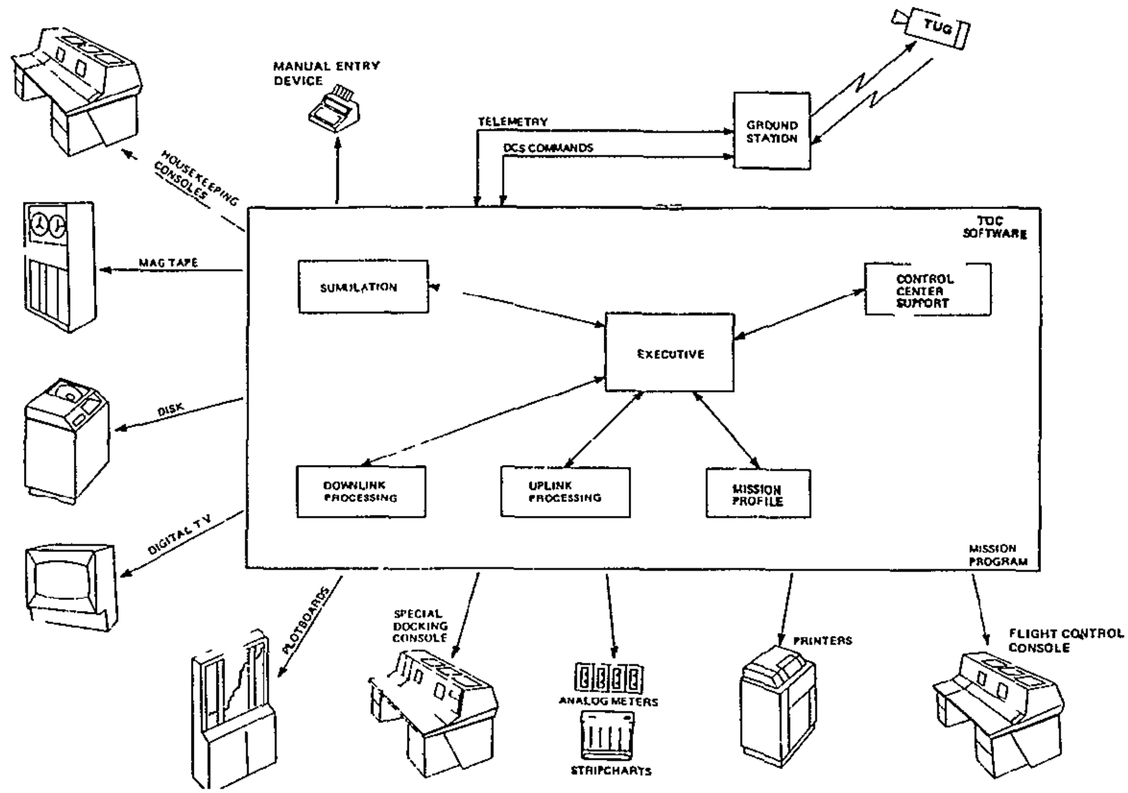

Figure 9 5 3-1 TOC Software Functional Interfaces

9 5.3 1 Vehicle System Software

To provide monitoring and control functions, the Control Center is required to maintain interface with the Tug vehicle through the telemetry downlink system and the digital command uplink system. The application software systems which provide these interface capabilities are the downlink processing and uplink processing software These critical subsystems are discussed in the following paragraphs

9 5 3 1 1 <u>Downlink Processing</u>

The downlink processing subsystem processes telemetry data received via the STDN (or TDRSS) from the Tug vehicle The data is processed in real-time and the results displayed to Flight Control personnel for system evaluation. The downlink processing capability is comprised of real-time processing, and telemetry support processing, each of which will be discussed in subsequent paragraphs This process is depicted in Figure 9 5.3-3 Size of the downlink processing software is shown in Table 9.5 3-2

Table 9 5 3 1 Instruction/Data Definition

INSTRUCTION/DATA EXAMPLE

PROBLEM Evaluate y as a function of time (t) according to the following expression

$$y = A + B_t + C_t^2 + D_t^2$$

Where A, B, C, and D are coefficients which determine the particular relationship between y and t

PROGRAMMING

INSTRUCTIONS are the sequence of machine operations required to evaluate the expression for y

DATA consists of the coefficients A, B, C, and D

DISCUSSION

Once the instructions for the evaluation have been tested, data can be changed without retesting of the instruction logic This reduces the cost of changing data words, whereas selection of a new evaluation technique will require complete redevelopment

Real-Time Telemetry Processing

The real-time processing capability consists of software to perform decommutation and conversion of input telemetry parameters utilized in real-time support of mission controllers and in performing analysis on telemetry parameters to provide system status data regarding the Tug vehicle. This process is shown in Figure 9.5 3-4 The major processing performed is discussed in the following paragraphs

Decommutation - The decommutation module of the downlink processor processes real-time telemetry data at the input message level Each message is validated for proper sequence by the ground site Formats of input messages are also validated

Through the use of a decommutation table, generated offline and loaded upon receipt of an input message, the decommutation module will unpack data from the input stream into data buffers utilized by telemetry conversion software. In addition, information pertaining to the location within the buffer of data is provided to user programs.

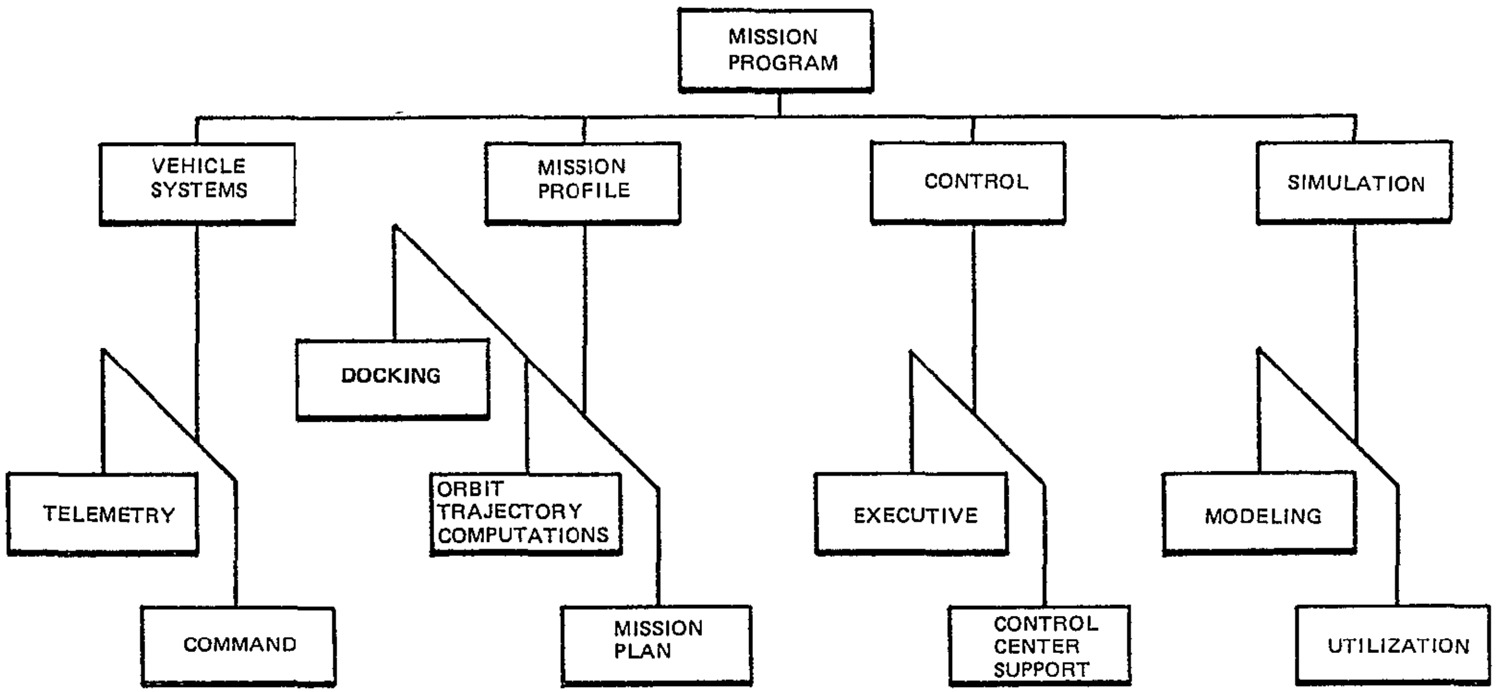

Figure 9 5 3-2 TOC Mission Software Structure

Table 9.5.3-2. Downlink Processing Summary

FUNCTION	NO OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
REAL-TIME TELEMETRY PROCESSING			
DECOMMUTATION	5,035	1,560	6,595
DATA CONVERSION	9,265	6,060	15,325
TELEMETRY SUPPORT			
DATA REDUCTION	28,305	2,520	30,825
DATA ANALYSIS	25,585	2,400	27,985
TOTALS	68,190	12,540	80,730

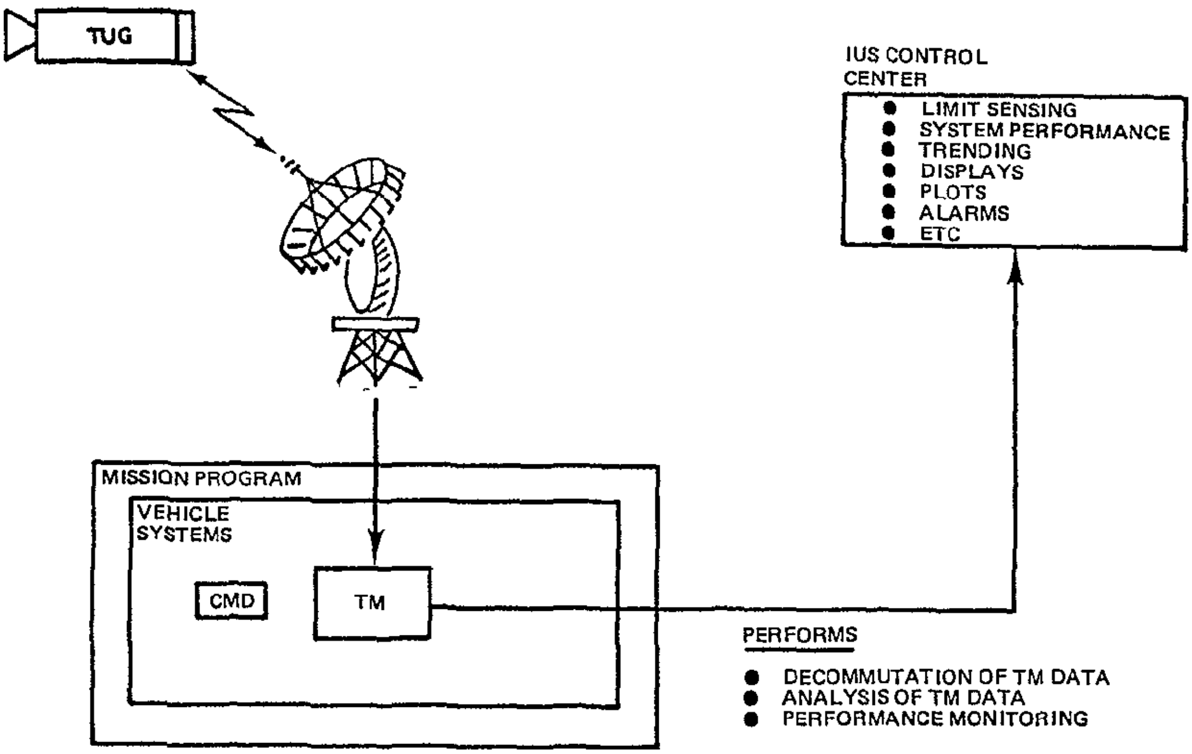

Figure 9.5.3-3. Downlink TM Processing

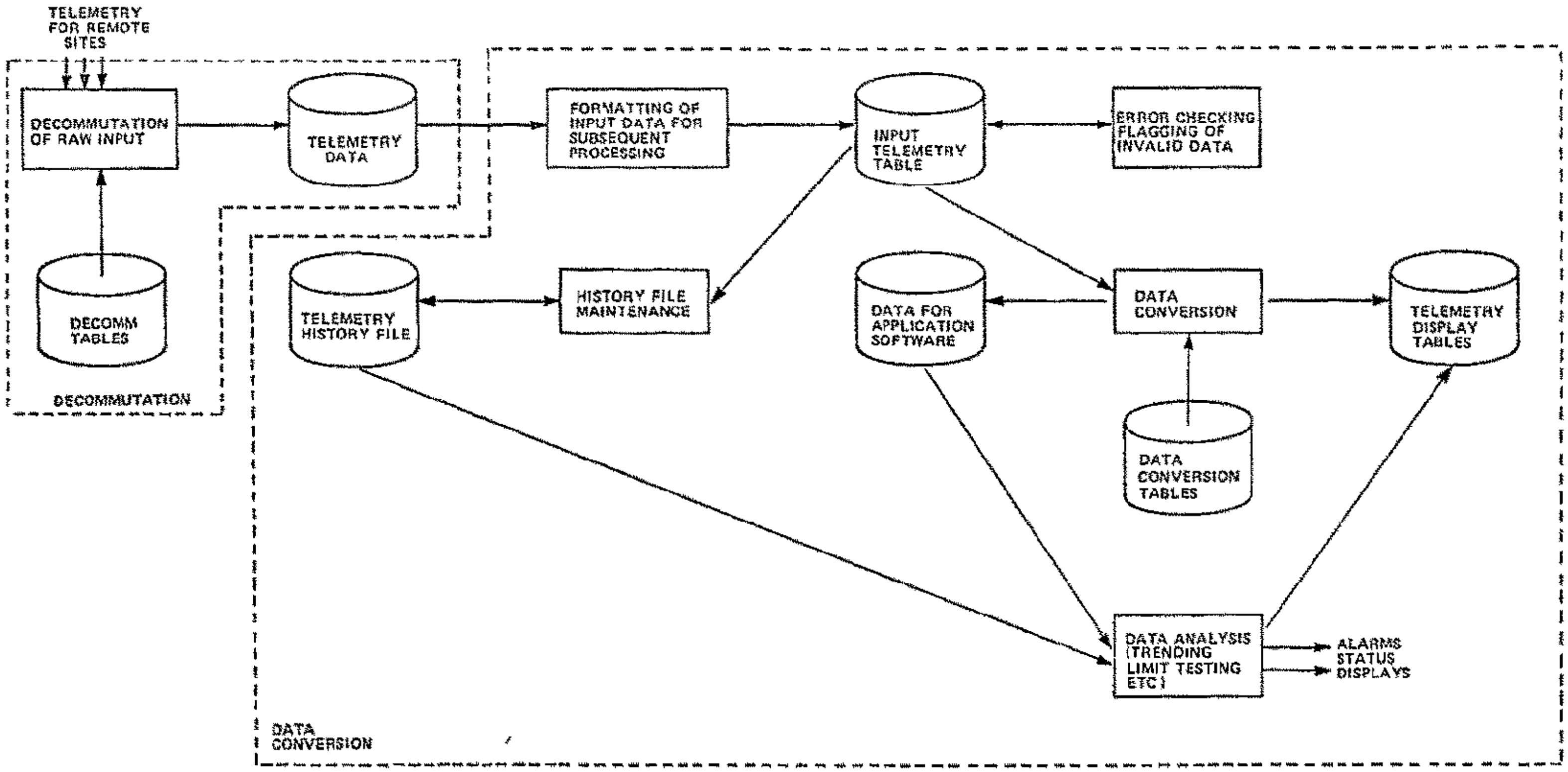

Figure 9 5 3-4 Real-Time TM Processing

Data Conversion - For use within the software subsystems and for display to mission controllers and other mission support personnel, the raw input telemetry data must be converted into a meaningful format This function is performed by the data conversion modules of the downlink processor through the following steps

- Data formatting
- Check for error conditions and set appropriate status indicators
- Maintenance of history buffers of input data
- Perform data conversions
- Store converted data into appropriate data areas
- Limit-sensing of converted data

Telemetry Support Processing

The telemetry support processing software is designed to operate in a non-real-time environmnet and is largely dedicated to the data reduction and data analysis of all parameters received via the downlink system The input to the telemetry support system is the telemetry history data gathered in real-time and saved on auxiliary storage devices for offline analysis. Outputs of the analysis are reports for use by flight controllers in evaluating overall system performance

Another function performed by the telemetry support software is the generation of tables to be utilized for real-time telemetry processing These tables contain the attributes required in processing each telemetered parameter and include such characteristics as scaling, calibration information, and limits on range Also included are critical event tables for use in monitoring correct Tug operation in real-time and display format tables for defining console support requirements

9.5 3.1.2 Uplink Processing

Uplink processing involves the formatting and transmission of commands to the Tug vehicle via the STDN (or TDRS) and the verification of network responses to those commands. The uplink processing software is comprised of three major functional areas whose responsibilities are (1) format and transmit all commands, (2) validate the transmitted commands and update command status displays, and (3) perform site and data management The overall functioning of the uplink processing software is discussed in the following paragraphs A functional diagram of the uplink processing is shown in Figure 9 5 3-5 and the size of the software is shown in Table 9.5 3-3.

Command Processing Control Program - The command processing control program is active in all aspects of uplink processing and performs the following functions

- Responds to requests for uplink processing
- Retrieves and initializes tables
- Handles communications among program modules utilized in uplink processing

Its overall prime function is to control the operations required in response to requests for uplink processing functions

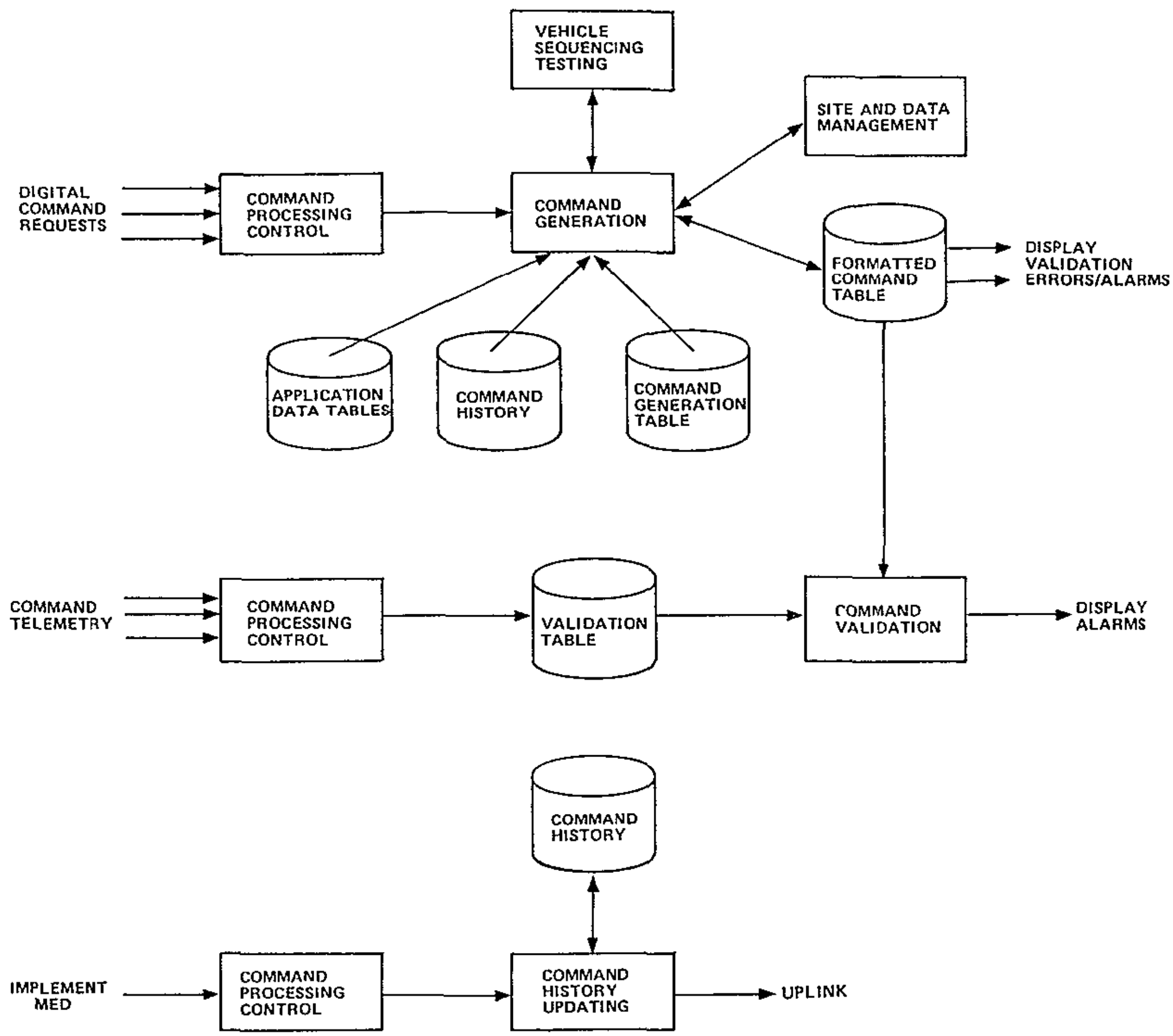

Figure 9 5 3-5. TOC Uplink Processing

Command Generation Program - The command generation program examines the input request and determines the command which is required Using data from the command processing data table and data acquired from other ground center software, the command is then formatted for transmission Prior to transmission, appropriate display tables are updated for mission controller verification of correct command format The command is then transmitted to the appropriate remote site ground station for uplink to the Tug vehicle.

Table 9 5.3-3. Uplink Processing Size

FUNCTION	NO OF INSTRUCTION WORDS	NO OF DATA WORDS	TOTAL
SITE MANAGEMENT	5,780	7,800	13,580
DIGITAL COMMAND PROCESSING	27,200	6,840	34,040
TOTALS	32,980	14,640	47,620

Command Validation Program - All commands transmitted to remote sites are 'echoed' back to the ground control center with status information indicating whether the command was accepted or not. In addition, the command validation program has a "time-out" feature in the event that no response is obtained from the remote site within the specified interval

The command validation program processes the 'echo' messages and will print messages for those commands flagged as invalid These print messages will indicate the command as well as the reason for invalidity Command messages successfully received by remote sites and verified are logged into command history tables.

Site and Data Management - The site and data management program updates the command-related displays for use by mission controllers The displays are only updated upon request for command processing and contain the following types of information

- Site management command history
- Overall command history
- Critical parameter changes executed through the uplink system
- Failure analysis history

9 5 3.2 Mission Profile Software

The mission profile software of the ground control center is primarily concerned with trajectory-associated functions The functional requirements satisfied within the mission profile software are listed below and are discussed in more detail in subsequent paragraphs.

- Orbit trajectory computations
- Mission Planning

The overall estimated size of the mission profile software is shown in Table 9.5.3-4. In addition, major subdivisions of the software are shown.

Table 9 5 3-4 Mission Profile Software Sizing

FUNCTION	NO OF INSTRUCTION WORDS	NO OF DATA WORDS	TOTAL
ORBIT TRAJECTORY COMPUTATIONS			
EPHEMERIS GENERATION AND CONTROL	22,100	4,050	26,150
STATION CONTACT CONTROL	8,640	500	9,140
MISSION PLANNING			
GENERAL MANEUVER PLANNING AND OPTIMIZATION	49,500	7,500	57,000
RENDEZVOUS PLANNING	29,520	1,980	31,500
MISSION PLANNING TABLE	--	36,000	36,000
TOTALS	109,760	50,030	159,790

9 5 3 2 1 Orbit Trajectory Computations

The orbit trajectory computations software is responsible for generation of current trajectory information In particular, it

- Maintains current orbital ephemerides which describe Tug vehicle trajectory containing periods of free-flight and/or powered flight.
- Maintains detailed information for currently planned maneuvers
- Computes numerous parameters for definition and evaluation of predicted Tug trajectories

The software to accomplish the above functions is discussed in the following paragraphs A functional description of the trajectory computation process is shown in Figure 9 5 3-6

Ephemeris Generation and Control

The ephemeris generation and control software generates, maintains, and references ephemerides for the Tug vehicle, the Space Shuttle, and the target vehicle The ephemerides provide rapid access and/or computation of trajectory dependent data for mission planning and real-time flight monitoring

The ephemerides are of two types, live or static A "LIVE" ephemeris describes the current trajectory of a vehicle. It is considered live because the

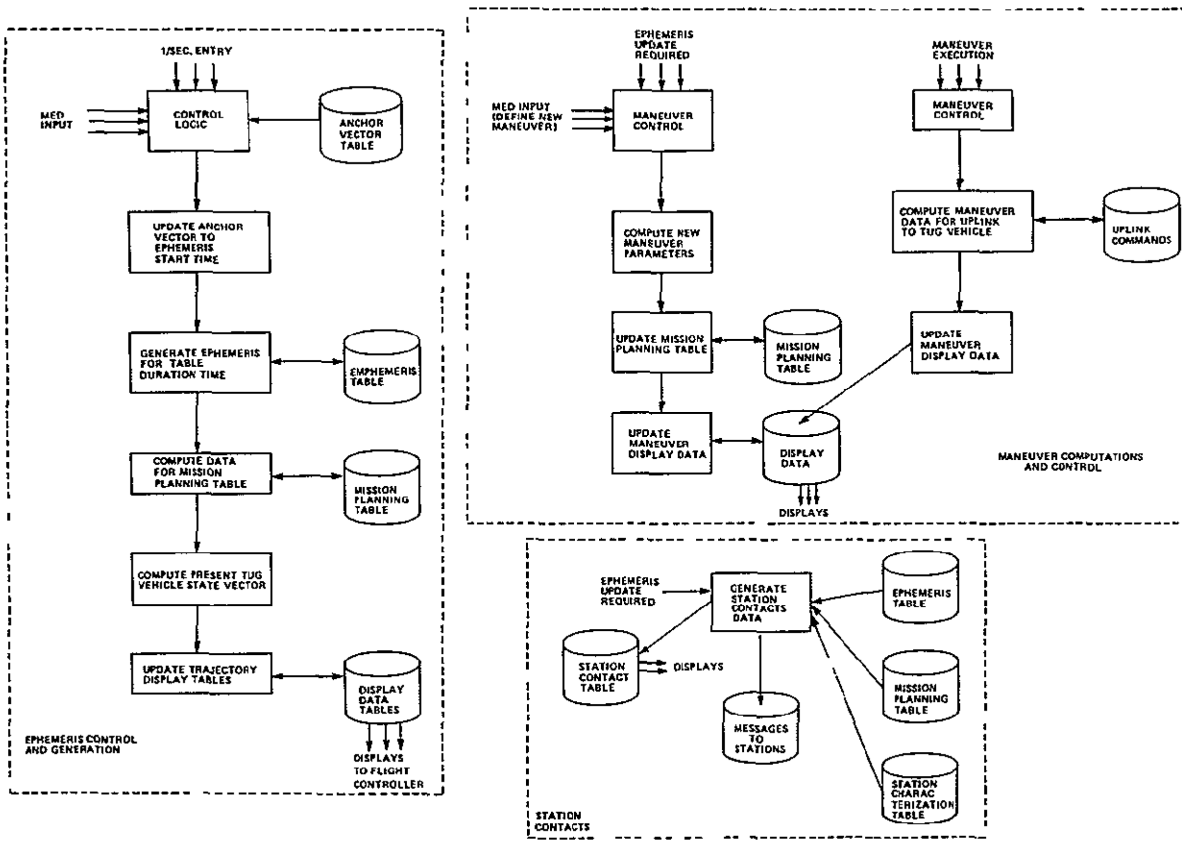

Figure 9 5 3-6. Trajectory Computation Process

trajectory is computed and output on trajectory evaluation displays for monitoring purposes In addition, the live ephemeris is advanced as current time processes. A "STATIC" ephemeris describes the predicted trajectory from an anchor vector whose time is anywhere within the mission profile The anchor vector is either specified by the user or defaults to the times of the last anchor vector specified The "STATIC" ephemeris, therefore, does not advance with time but instead remains fixed at the defined base state

Ephemerides have the following additional characteristics

- Each can contain periods of free flight and/or powered flight
- Density of each ephemeris is three minutes for free flight periods and 10 seconds of powered flight periods.

The ephemeris generation and control software is subdivided into three major areas (1) control logic, (2) ephemeris generation logic, and (3) display requirements These areas are addressed in the following paragraphs

Control Logic - The control logic performs initialization and supervisory functions necessary in maintaining and referencing vehicle ephemerides There are five categories of processing within the control logic (1) input processing, (2) anchor vector table maintenance, (3) vector routines, (4) trajectory update supervision, and (5) miscellaneous vector processing The following steps are executed in performing these functions

- Vector for a specified vehicle ephemeris is entered via manual entry device
- Vector is stored in anchor vector table
- Ephemeris vector is generated
- A trajectory update is performed utilizing new anchor vector
- Miscellaneous vector routines are used to perform trajectory computations

Ephemeris Generation - The ephemeris generation software performs the actual generation of a vehicle ephemeris and updates the necessary tables to reflect the current trajectory Since each ephemeris can contain periods of free-flight and powered flight, the software updates the ephemeris table with both types of vectors

Display Requirements - This portion of the ephemeris generation and control software provides the capability to display ephemeris associated data to flight controller personnel These displays contain the following types of data

- Vehicle state vector at specified time
- Earth-referenced position at specified time
- Arrival time and orientation at specified point
- Current vehicle state vector
- Time-to-go to specified position

Station Contacts

The station contacts software determines when the Tug vehicle and radar ground stations are in contact with each other, displays this data, and informs the remote station of upcoming contact periods To accomplish these functions, the software has been divided into the following areas

- Station contact generation
- Station contact displays
- Remote site acquisition

Station Contact Generation - The programs in this unit generate orbit station contact information based on specified ephemeris. The mathematical models required to determine horizon crossing times, terrain masking effects, and keyhole loss of signal times are maintained When given site definitions and ephemeris data, the program will generate a chronological list of station contacts.

Station Contact Displays - The station contact displays software produces information about present and future station acquisition and parameters associated with those contacts.

Remote Site Acquisition - The transmission of acquisition messages to the remote tracking stations is the function of this software. Information contained within the messages is as follows

- Slant range, receiver frequency, transmitter frequency, bias doppler, and one way doppler to S-Band stations
- Pointing data for tropospheric refraction

9 5 3 2 2 Mission Planning

The mission planning software will provide the capability, under control of mission controller entry, to produce displays for use in evaluating the current trajectory's ability to satisfy mission objectives In addition, the ability to produce and evaluate alternate flight plans will be provided

The mission planning software is composed of two basic elements - the mission planning table and the mission planner.

Mission Planning Table - The mission planning table is the focal point of the trajectory computation software and contains the following information

- Ephemeris data
- Maneuver data
- Vehicle attitude data
- Sequencing data
- Station contact data
- Rendezvous plan

The initial mission planning table is created prior to the Tug mission to satisfy the objectives of a nominal mission. During the mission, the table can be updated to reflect the actual mission profile and can also be used for contingency planning purposes

Mission Planner Program - The mission planner program will be utilized in the evaluation of the Tug trajectory and in the generation of new flight plans resulting from contingency situations. The mission planner will function in

an interactive environment with the flight controller Displays will be produced for evaluation by the flight controller Selection of a new flight plan will result in the new trajectory's description being used to generate new ephemeris and mission planning tables A functional diagram of the mission planner is shown in Figure 9 5 3-7

The principal use of the mission planner will be in contingency planning

Contingency Planning - The mission planner will use the mission planning table to support the need for contingency planning in real-time Flight controllers will be able to introduce general data for evaluation and the mission planner will

- Determine the effects that a given incremental velocity applied along a specific axis will have on the mission profile

- Determine the desired maneuver required to change from the present orbit to a specified orbit

Information provided for contingency planning will be entered into the mission planning table only if the flight controller selects the new plan for implementation

9 5 3 3 Control Software

The Control Software provides the capabilities to control overall software execution and interface with Flight Support Facilities A diagram of the functioning of the Control Software is shown in Figure 9 5.3-8

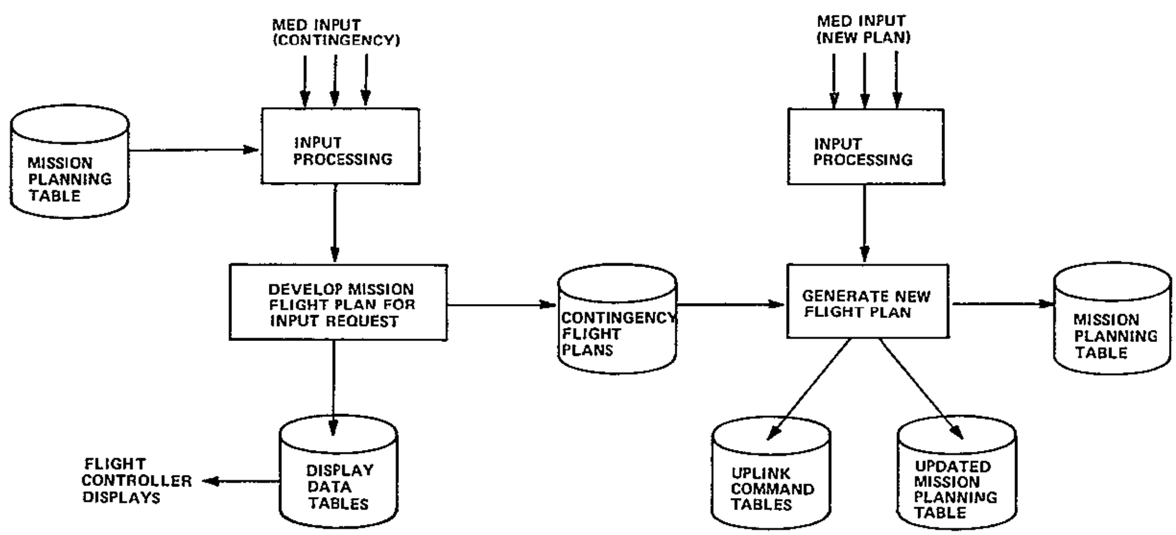

Figure 9 5 3-7 Mission Planner

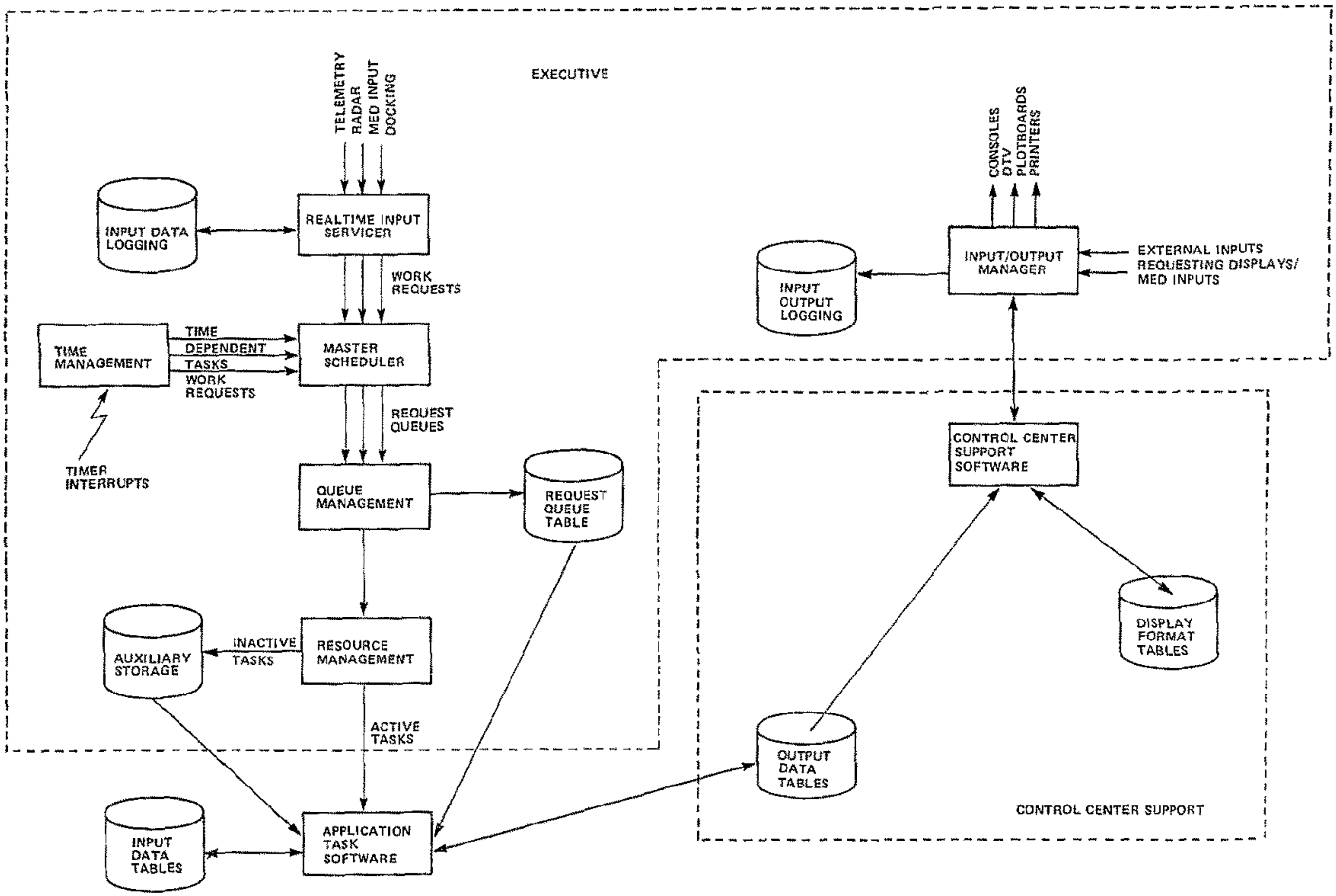

Figure 9 5.3-8. TOC Control Software

9 5 3 3 1 Executive

The executive program functions as the supervisor of the application software within the central computer and controls and sequences all input/output activity In addition, the software within the executive will provide the capability to recover from component failures within the control center without degrading system integrity The subelements which comprise the executive and the size of the executive software are shown in Table 9 5 3-5

Table 9.5 3-5. Executive Software Summary

FUNCTION	NO OF INSTRUCTION WORDS	NO OF DATA WORDS	TOTAL
TASK MANAGEMENT	74,127	5,321	72,448
APPLICATION TASK CONTROL INITIALIZATION ERROR RECOVERY QUEUE MANAGEMENT MASTER SCHEDULER OPERATING SYSTEM UTILITIES			
DATA MANAGEMENT	74,281	7,683	81,964
RESOURCE MANAGEMENT DATA LOGGING STATISTICS GATHERING AUXILIARY STORAGE OPERATING SYSTEM UTILITIES			
INPUT/OUTPUT MANAGEMENT	29,492	4,369	33,861
I/O CONTROL INTERRUPT HANDLING OPERATING SYSTEM UTILITIES			
SYSTEM INITIALIZATION	33,000	11,931	44,931
TOTALS	210,900	29,304	240,204

The executive program is designed to

- Minimize the application system hardware dependence
- Ensure fast response to system activity
- Provide simplicity to application program development
- Provide the support to application software in handling large amounts of real-time data
- Provide a flexible base for future expansion

The major functions provided for application software are task management, data management, input/output management, system initialization and simulation support These major functions are discussed in the following paragraphs. Reference should be made to Figure 9.5 3-8 to follow the interfacing of the subelements discussed following

Task Management - The task management capability of the executive is built upon the independent task concept In this concept, an independent task is able to receive work at all times regardless of the input data rate. When data is received by the system for a task, it is sent in the form of a request Each request has its own priority which in turn becomes the priority of the task If a task is processing a request and a new request is received from the task, the new request is held according to its priority and processed upon completion of the request in progress

Each task is assigned an area in main storage called a resource table This is a private area that can be used by the program running under the task In addition, each task is assigned a unique protect key which protects it from all programs controlled by other tasks

Master Scheduler - The master scheduler examines all input data and acts as an interface between the hardware interrupt servicing function and the task management function When the master scheduler receives an input message, it compares the message with the current data definitions If a compare exists, the message is routed to the task which will process it If no compare exists, the message is discarded. The master scheduler can also accumulate a number of messages for the same task and generate a request for the task after the specified number of messages have been received In this case, all the accumulated messages will be sent to the task as one request

Within the Control Center, work requests will also be generated according to elapsed time. For example, a task may be created to control a load module which updates the position of the vehicle every second The only data necessary to perform this operation is the previous position and the orbital parameters Since this data exists within the software system, no external signal will occur to request execution of the task. In a case such as this, the request will be generated through a timer interrupt under control of the software This technique for task requests is known as time routing

Time Routing - Time routing is used within the Control Center software to generate work requests on specified time intervals It functions as the interface between the time management function of the executive and the task management function. When an application program requests a series of time dependent activations, the time routing program sends the request to time managment specifying the time when the next request should be generated When the timer interrupt associated with the request is received, time management will call the time routing function which, in turn, will call the required task

Queue Management - As mentioned previously, if a task is processing a work request, all other requests for that task must be held by the system until the task is available for further processing To support this operation, the executive must build and maintain a queue of work requests waiting to be processed by each active task Information concerning each request is held in a real-time queue element

Each active task will be processing one work request and that request is represented by the active queue element All other requests for the tasks will be placed in the queue of 'waiting' elements Requests from the 'waiting' elements are ordered according to priority, in the case of equal

priority, first-in first-out (FIFO) is the order of processing When the task completes, the request of high priority is made active and passed to the task for processing If no 'waiting' requests exist, the task becomes dormant awaiting new data for processing

If queue management is not provided, the queue elements can accumulate indefinitely unless the tasks can process their work requests faster than they are generated Queue management provides the capability to control requests by limiting their number It can also be used to control system load by not giving requests to a task until other tasks are complete

Time Management - The computer to be utilized within the Tug Control Center will be equipped with a special high resolution GMT clock and interval timer To provide support for these timer devices, a time management supervisor will be required within the executive The supervisor maintains system time and controls the setting and interrupt handling functions resulting from the timer hardware

System Recovery - It is of prime importance that the software continue to function in the presence of errors or failure conditions Three areas of software are required to address switchover, high-speed restart, and error recovery

For system reliability considerations, a backup main computer system will exist within the ground control center The ability to select the backup computer system without interruption to the input/output processing of real-time data or degradation of mission output will be performed within the executive program

In the event of computer failure, the backup computer system must be brought online within a minimum specified time interval An initial load program will exist within the executive to transfer all required data from the operational system to the selected backup system

The error recovery function of the executive pertains to errors resulting from program checks, hardware malfunctions, or abnormal conditions arising within the software system itself In effect, error recovery capability is restricted to those errors recognizable within the software for which software action can be taken The error recovery programs will print appropriate messages and recommendations regarding system status

Operating System Utilities - The executive program for the Tug Control Center will be built around the capabilities of the operating system provided with the computer This approach will allow utilization of existing system software and will provide a standard base for development of application software In addition, the utilization of the computer's operating system will allow one control center computer to be used for normal job processing when not being used for real-time mission support

Input/Output Management

Because of the real-time nature of input/output processing, special techniques must be provided to handle this activity efficiently and rapidly These techniques are included in the following functional areas of the input/output management software

- Real-time access method
- Real-time interrupt servicer and start-stop input routing
- Digital/TV display control
- Shared device support

Real-Time Access Method - The real-time access method performs device dependent data manipulation and output messages to special real-time devices within the Tug Control Center It also is used to control the reading of information from the display hardware used by flight controllers Output to all display hardware is also controlled by the real-time access method

Real-Time Interrupt Servicer and Start/Stop Input - The real-time interrupt servicer and start/stop routines provide control over the input from real-time input devices within the control center. The servicer passes the request information to the master scheduler for use in scheduling the execution of the appropriate task The start/stop input routine controls the initiation and transfer of data from the input device and can stop the transfer in the event of failure

Digital/TV Display Control - The digital/TV display control program provides support to the digital TV stations within the ground control center It services all digital TV display requests, maintains information regarding which displays are currently being viewed and the consoles viewing them, controls the dynamic allocation of the digital/TV channels, and generates the request for tasks which supply data for use in updating displays

Data Management

The data management portion of the ground control center executive performs the functions of·

- Data logging
- Data table maintenance
- Auxiliary storage control
- Background utilities

The functional discussions of these elements are contained in the following paragraphs

Data Logging - In a real-time environment, it is essential that a technique be provided which saves the data received, transmitted, and processed by the system Within the control center, all such data is recorded on magnetic tape In addition to system inputs/outputs, application program data can be recorded for program checkout purposes

Data Table Maintenance - Because of the large amounts of data which must be accessed and manipulated during support of a Tug mission, a series of control programs will be utilized to support data table handling.

Data tables are blocks or arrays of data maintained on direct access devices Through use of data table control software, tables can be 'logged' to ensure data integrity and consistency during a read operation. This will delay any tasks attempting to write into the table until the data has been 'unlocked'.

Each data table is identified by a name field and is defined by its block size and number of blocks. A data table generation program uses these parameters in allocating space for each table and providing the controls required to access it.

Auxiliary Storage Control - Because the overall software size for the control center will exceed the capacity of the computer's main memory, direct access devices will be used to store all programs not required to reside in memory at all times. The retrieval of these programs from auxiliary storage in real-time and the dynamic loading into main memory are functions performed by the auxuiliary storage control software.

Background Utilities - Numerous capabilities have been included in the executive for use in background operations which can be initiated or terminated by console operation. These background utilities execute asynchronously with normal operation and provide the following capabilities

- Dump auxiliary memory to tape
- Restore auxiliary memory from tape
- Clear auxiliary storage device
- Copy a tape
- Compare tapes
- Print magnetic tape

Statistics Gathering System - The statistics gathering system provides timing information and execution frequency statistics useful in accessing overall system performance. Example of the types of statistics are given below

- CPU Performance - shows the amount of CPU utilization, the time spent waiting on I/O, or time spent in gathering statistics

- Load Module Performance - shows the execution frequency, average execution time, percent of CPU utilization, and number of requests for each task

- Task Performance - shows the number of task executions per specified time interval and the execution time for task

- Executive Performance - shows the percent of CPU utilization spent in performing executive functions

System Initialization

Prior to initiation of the application software to support a Tug mission, the executive will perform the necessary diagnostics on system hardware, configure the hardware in accordance with input specification, and initialize the application software to accept task requests.

The system initialization software will reside on auxiliary storage devices and will be loaded into main memory under control of the computer's operating system. The initialization software then controls the loading of remaining

software into main memory and will pass control to the task management function when all initialization tasks have been completed The main memory utilized by system initialization then becomes available for system use

Simulation Support

To assist in development of the application software, the executive program has two features which provide significant testing capability These features, discussed below, are simulated input control (SIC) and fast time.

Fast Time - Fast time is a capability of the executive to stop the time reference if no software activity is scheduled In this way, many hours of computer time and programmer time can be saved Using this capability, the input messages are processed as rapidly as the tasks can be run.

Simulated Input Control (SIC) - Simulated input control provides the capability to send simulated input data into the application software for test purposes This input data can be in the form of cards or tape or both. All data has the time of receipt associated with each message and SIC routes each data message to the master scheduler for scheduling of the required task. For convenience, SIC will allow data log magnetic tapes to be used as source for simulated input. In this manner, actual data obtained from previous flights or simulations can be used as a test bed for software change verification.

9 5 3.3.2 Control Center Support Software

As was discussed previously, the executive program provides the input/output capability to interface with the hardware devices within the control center In addition to the software existing for input/output, significant software is required to format data properly for output, to provide the data requested, and to maintain the data base required for display purposes. A functional description of the control center support software's relationship to the executive and hardware external to the computer system is shown in Figure 9.5 3-8 Sizing data is shown in Table 9 5.3-6

Table 9.5.3-6. Control Room/Display Management

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
DISPLAY DEVICE INPUT SERVICING	1,904	400	2,304
DISPLAY DEVICE OUTPUT	10,786	2,840	13,626
TOTALS	12,690	3,240	15,930

9 5.3.4 Simulation System Software

In the development and qualification of the control center, data from external sources such as remote sites, Tug vehicle, etc., will not be available on a

continuing basis In addition, certain hardware systems within the control center may not be available when needed to support testing To provide an environment to assure the capability to perform testing at all times, development of a simulation capability will be required This simulation capability will be performed through software modelling of the control center environment The simulator will provide simulated real-time inputs, under control of simulation personnel, to test both the nominal and contingency capabilities of the control center

Simulations have been utilized in both the Mission Control Room at JSC and at the Deep-Space Control Center at JPL with significant results For the Tug Control Center, the simulation system will be used to address testing requirements associated with hardware checkout, software development, procedural verification, and ground controller training

The subelements which comprise the simulation system are shown, with corresponding sizing information, in Table 9 5 3-7

Table 9 5 3-7 Simulation System Size

FUNCTION	NO OF INSTRUCTION WORDS	NO OF DATA WORDS	TOTAL
TUG VEHICLE SIMULATION	56,250	16,560	72,810
GROUND STATION SIMULATION	49,500	7,500	57,000
TCC SUBSYSTEMS SIMULATION			
DISPLAYS	10,800	19,800	21,600
MED ENTRIES	13,500	5,400	18,900
SIMULATED INPUT CONTROL	6,750	6,780	13,530
TOTALS	136,800	47,040	183,840

9 5 3 4 1 Simulation Description/Operation

The overall functional description of the simulation system and its relationships with the operational software and hardware of the control center are shown in Figure 9 5.3-9 The simulation system contains models of the following operational components·

- Tug vehicle
- Ground station
- Subsystems within the control center, such as displays, consoles, and panels

To provide a near real-time environment, the simulation system software will be executed within the backup central computer system The primary central computer will contain the operational software of the control center The simulation software will perform all modelling, as requested by the simulation controller, and provide inputs to the operational software Outputs

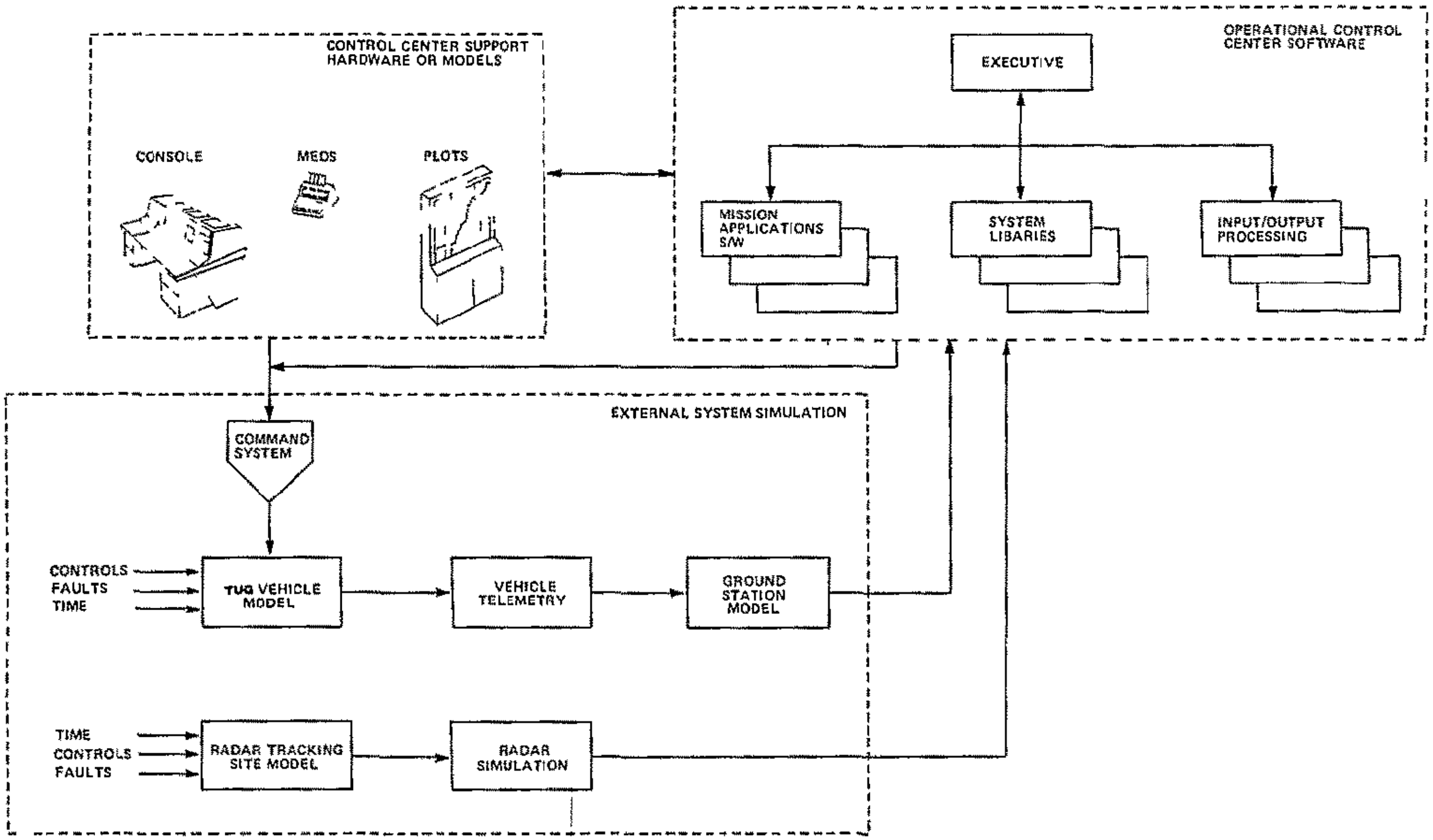

Figure 9 5 3-9. TOC Simulation Software Interfaces

of the operational software will be directed to the control center hardware or simulated models Uplink commands will be routed to the simulation system rather than to remote sites Through this operation, a closed-loop simulation is achieved which will provide significant flexibility in the overall testing plan for the control center

The elements of the simulation system are discussed in the following paragraphs

Tug Vehicle Model - The model of the Tug vehicle is a detailed mathematical model which includes the following onboard systems

- Onboard computer (includes onboard computer software)
- Guidance
- Telemetry
- Stabilization and control
- Reaction control
- Propulsion
- Sequential events
- Attitude sensors
- Uplink command
- Power
- Payload

Ground Station Model - The ground station model will accept as input the telemetry data generated by the vehicle module and will generate telemetry data in the format acceptable to the Tug Control Center software

Control Center Hardware - Since a signficant portion of the simulation will be controlled from flight consoles and manual entry device inputs, this control center hardware will be modelled within the simulation system

For MED inputs, tables of input data to be executed as a function of mission time will be established prior to the mission simulation As the mission is simulated, these inputs will be issued at the appropriate time Each issuance will be logged for post-simulation analysis, and, in addition, tests will be conducted, during the simulation, on response of the operational software to the stimuli issued through the MED simulation

Display simulation will test the capability of the operational software to properly respond to display requests and display properly formatted data The display data will be logged for post-simulation analysis Correlation between the data generated by the simulation and that calculated and displayed will be accomplished during the simulation and logged for analysis

Simulated Input Control - The simulated input control, although a subset of the simulation system, is a 'stand alone' simulation tool for selective entry of data into the operational software This capability provides a means of performing software checkout without the overall simulation system being involved. The input is largely manual and provides a tightly controlled testing environment

9 5 3.4.2 Simulation System Utilization

As was stated previously, the prime uses of the simulation system are

- Hardware checkout
- Software development
- Procedural verification
- Flight controller training

Hardware Checkout - Through use of the hardware simulation capability, a data base can be provided for comparison between actual hardware and modeling test cases Replacing software models with actual hardware also provides verification of system interfaces prior to overall system testing.

Software Development - The simulation system will be utilized to provide inputs, during software development, for program checkout purposes. Because of the input control features of the simulation system, predictable test cases can be generated and conducted This use of the simulation system will provide a base for systematically testing the operational software in a realistic environment and will allow testing to proceed at the overall system level before requiring the participation of outside activities

Procedure Verification - Prior to each Tug mission, a flight plan will be generated This flight plan will detail the procedures to be followed to ensure that the Tug mission achieves all objectives. The simulation system will provide the test bed to verify that the procedures are correct.

Flight Controller Training - Flight controllers must be trained to handle all contingency situations In view of the criticality of flight controller expertise, a thorough training program prior to the actual mission must be provided.

The simulation system is ideally suited to provide the training needed by flight controllers The simulation system in conjunction with the control center software can reproduce all nominal events and non-nominal contingencies which may occur during a mission The active participation of flight controllers in overall system simulation will ensure that the controller is thoroughly familiar with available mission support tools, data and will provide training in a real-time environment

9 5 3 5 Software Summary

This section of the Tug study report has identified the functional software requirements which must be satisfied in order to control the Tug vehicle from a control center. The overall size of the software has also been addressed and is summarized in Table 9 5.3-8.

The primary emphasis has been placed on ensuring that all the functional requirements have been addressed. The software size, which has been developed, is based on a study of similar software at the JSC-RTCC and JPL-DSC. As can be seen in Figure 9 5.3-10, the Tug software size is less than previous ground control center software for other space programs, however, as the Tug control center requirements are more clearly defined, the software may grow.

Table 9 5 3-8 Tug Control Center Software Summary Size

FUNCTION	NO OF INSTRUCTION WORDS	NO OF DATA WORDS	TOTAL
DOWNLINK PROCESSING	68,190	12,540	80,730
UPLINK PROCESSING	32,980	14,640	47,620
MISSION PROFILE	109,760	50,030	159,790
EXECUTIVE SYSTEM	210,900	29,304	240,204
CONTROL CENTER SUPPORT	12,690	3,240	15,930
SIMULATION SYSTEM	136,800	47,040	183,840
TOTALS	571,320	156,794	728,114

9 5 4 AIRBORNE OPERATIONS SUPPORT SOFTWARE

The Flight Software requirements for a Level II Tug vehicle are estimated, based upon the anticipated share of the mission operations decision requirements Four baseline flight programs have been postulated, and the specific mission implementation is to be a modular adaptation of one of the baseline programs The following paragraphs discuss the general approach to the Tug Flight Program.

The flight program is an integral part of (1) the guidance and control system comprising the central computer, data bus, IMU, star tracker, sun sensor, Landmark Tracker, Rate gyros and the flight control electronics, and (2) the Tug sequencing system comprising the discrete input, discrete output, and interrupt processing of the central computer

The integration of these systems is accomplished through the flight program It provides a flexible mechanism by which the system functional and detailed specifications may be altered, within wide limits, to accomplish a wide variety of missions without changes to the vehicle hardware

Although specific requirements will vary with mission phase, the flight program is required to provide for the following recurring functions

- Navigation
- Guidance
- Attitude Control
- Sequencing
- Telemetry
- Programmed backups to specific hardware functions
- Command processing
- IMU processing

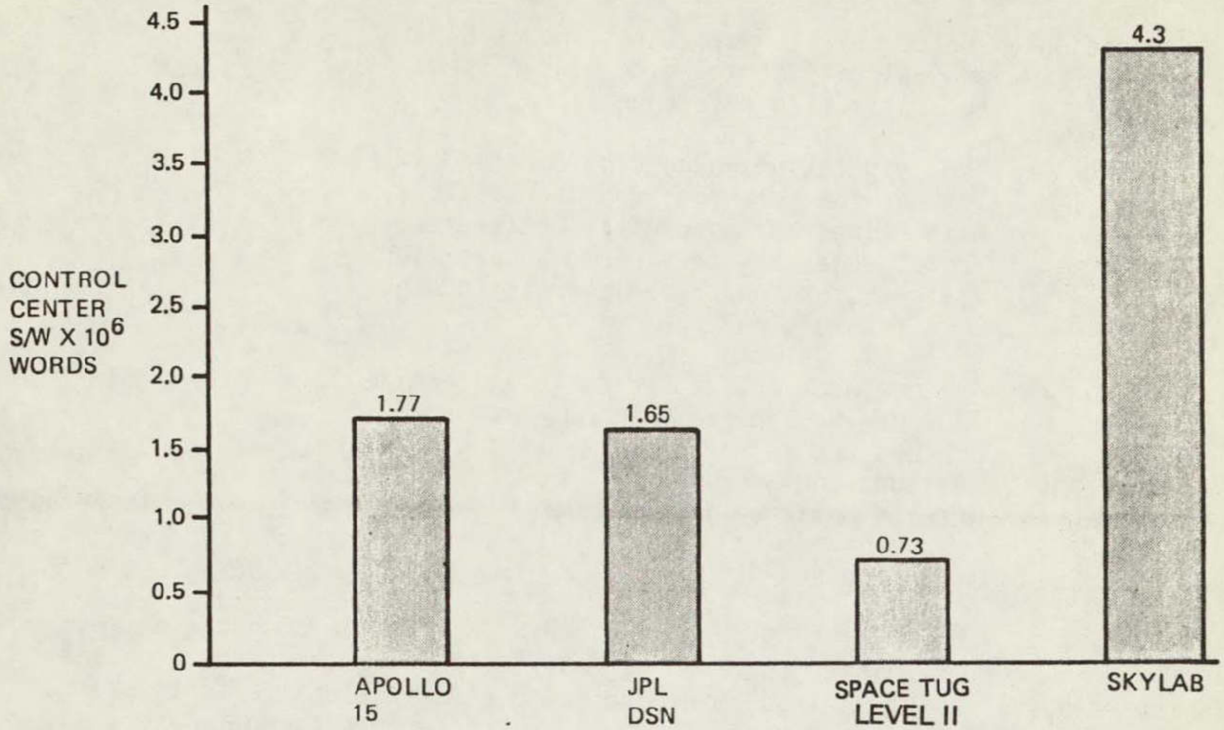

Figure 9.5.3-10. Space Programs Mission Software Size

9.5.4.1 Non-Recurring Functions

The one-time targeting requirement is performed at approximately two hours prior to shuttle liftoff. The targeting parameters are loaded via the LPS with a backup load performed by ground DCS command if required. The variable target optimization capability provides data loads to the flight program assuring optimum performance dependent data.

9.5.4.2 Recurring Functions

Of the recurring functions listed above, command processing is required for the one-time targeting requirement and during the orbital mission phase. The remaining functions are required during both the boost and coast phases although specific requirements and rates of computation may vary from the boost to the coast phases. Each requirement is discussed separately except for navigation and guidance which are more closely tied together than the other requirements. In addition, the guidance law and navigation scheme requirements are significantly different during the boost and coast phases. Therefore, these two requirements are combined in the discussion and this particular discussion is broken into boost and coast mission phases.

The following definitions of navigation, guidance and control apply in this document.

Navigation: The calculation of vehicle position and velocity at any time with respect to a specified reference frame.

Guidance: The computation, according to a specified law, of instantaneous vehicle attitude, with respect to a specified reference frame, necessary to achieve a specified state vector and/or vehicle attitude at some future time.

Control: The computation, according to a specified law, of the vehicle commands necessary to achieve the required instantaneous vehicle attitude and operation of the proper hardware to position the vehicle.

9.5.4.2.1 Boost Navigation and Guidance

Since variations in acceleration are large during boost, the computation rate for navigation must be higher than during coast. In determining position and velocity relative to the desired reference frame, gravitational effects are computed as part of the navigation scheme since the sensors cannot measure gravitational acceleration. A mathematical model of the earth's gravitational field, which was empirically derived from satellite measurements, will be used in the gravitational computations. Position and velocity in the desired reference frame are obtained by differencing the integrated measured and gravitational accelerations. The computation rate, or integration interval will be variable. With these rates, and the smoothed acceleration function, a simple trapezoidal integration routine yields sufficient accuracy. A single navigation scheme is adequate through the boost phase.

In order to achieve the correct orbital inclination and longitude of descending node, active guidance is required in both the pitch and yaw planes. Compensation in the guidance law is required for abrupt transients in vehicle performance and for subtle off-nominal vehicle characteristics such as center of gravity offsets. In general, active guidance laws, including IGM, tend to become unstable as the end conditions are approached. In order to maintain a stable vehicle at cutoff, certain of the guidance constraints will be dropped shortly before cutoff. In particular, the position constraints, and the lateral and vertical position rate constraints are dropped as the time-to-go approaches zero. The component velocity-to-be-gained constraints are maintained slightly longer and the commands "frozen" just before cutoff to ensure zero angular rates and a stable vehicle. The time of cutoff is computed as a function of total velocity-to-be-gained and the cutoff command issued to the Tug at the proper time. The primary constraints on the orbit are inclination and longitude of descending node. The constrained insertion conditions are radius, path angle, and velocity.

9.5.4.2.2 Orbital Navigation and Guidance

The Space Tug will have a self-contained navigation system that does not rely on a dedicated ground support system for earth reference data. Earth reference

data is acquired continuously and processed in real time to establish Spacecraft position and velocity Advances in digital processing hardware and software technology and earth reference sensors have made autonomous space navigation systems practicable.

Accurate navigation of the Space Tug with respect to the earth requires sensing an appropriate earth feature in some portion of the electromagnetic spectrum Best results are achieved when these earth features and the performance of the electromagnetic sensors do not vary with seasonal, diurnal, and atmospheric changes. For these reasons IBM selected, as landmarks of known position (latitude, longitude, and altitude), ground radars operating in the 2.5 to 3 5 GHz portion of the electromagnetic spectrum Air traffic control, defense early warning, coastal search, and navigation radars, which are numerous and distributed worldwide, satisfy these requirements Since there are more than 8000 such radars operating 24 hours/day, radiation in this frequency spectrum has essentially become part of the natural environment

System Concept

The key element in the Space Tug autonomous navigation system concept is the Interferometric Landmark Tracker (ILT), which provides accurate angular tracking of the radar landmarks This strapped-down sensor, composed of two orthogonal phase interferometers operating in the E/F frequency band, provides a 120 degrees field-of-view and permits continuous tracking of one or more radars without mechanical or electronic scanning This performance is independent of cloud cover or time of day. Figure 9 5 4-1 illustrates the concept

The strapped-down star sensor and inertial reference unit, in combination, provide an attitude determination system (ADS) that establishes an inertial attitude reference ($\pm$15 arc seconds) for the ILT angular measurement. The necessary computations to process the ADS measurements in a 6-state digital filter and navigation measurements in a separate 16-state digital filter are carried out in the on-board digital computer A radar altimeter, operating only over the seas and oceans, is included to limit the increase of position and velocity errors during long periods between landmark sightings The altimeter is operated for 1 second every 10 minutes, making minimal demands on average power and limiting Space Tug detectability

From the available radars within the frequency band, 343 have been selected as landmarks. Wherever possible, these are distributed to provide latitude "chains" at 60 degrees, 45 degrees, and 30 degrees North latitude and along coastlines to provide longitude bands. The 343 radars provide redundant landmarks in the northern hemisphere, that is, landmark pairs have been selected such that two landmarks are simultaneously within the field-of-view of the ILT. This ensures landmark availability during maintenance or other down time of any radar landmarks Because of the scarcity of land, and consequently radars, in the southern hemisphere, nearly all usable radars in this hemisphere are included in the landmark table.

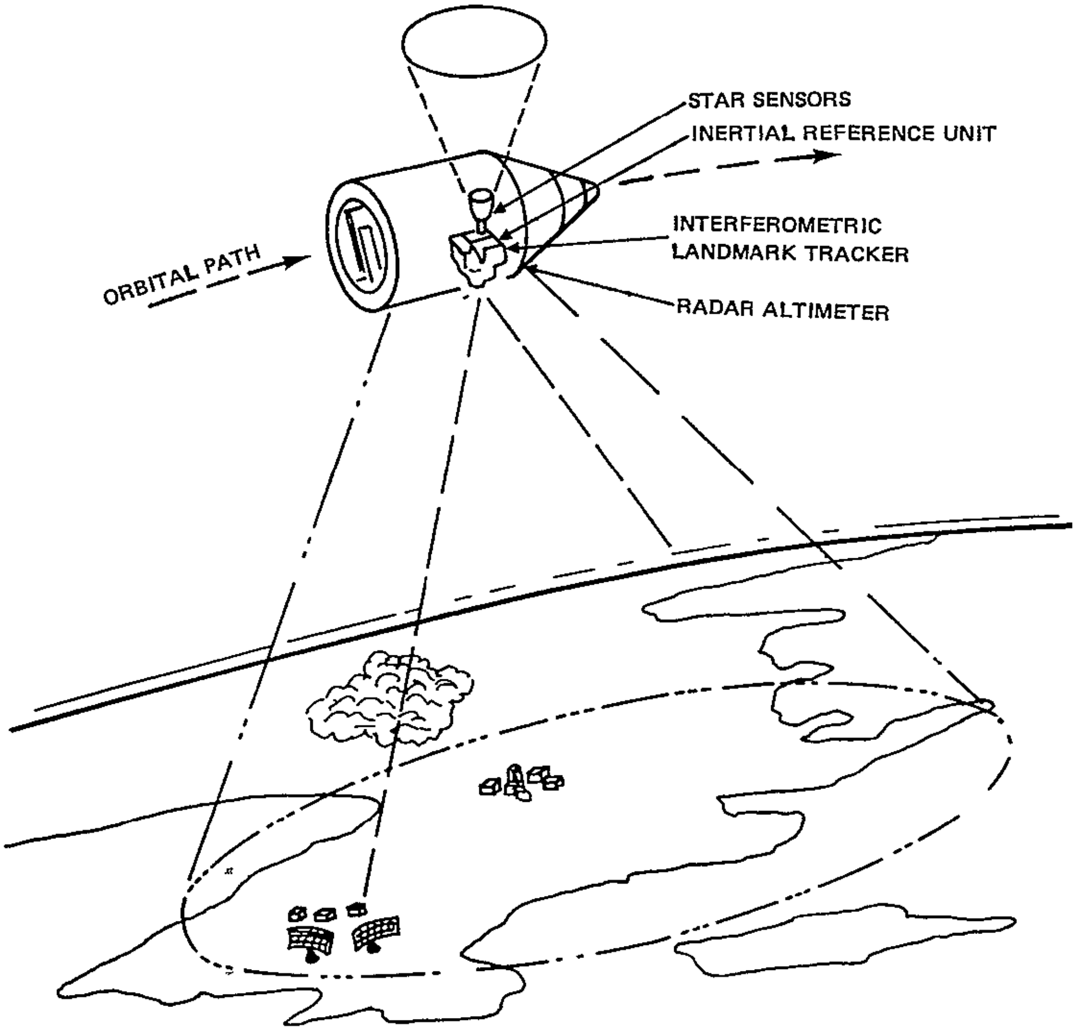

Figure 9 5 4-1. Interferometric Landmark Tracker Navigation System Concept

The landmarks are stored in the computer in tabular format, organized in latitude bands and ordered by longitude Landmark latitude, longitude, altitude, and frequency are stored in three 16-bit words, hence, the total landmark table, which permits navigation over all orbital inclinations, requires 1029 words of computer memory. (If the storage were optimized on a mission basis, only about 250 words would be required) Typically, 12 landmarks per orbit are observed in low-altitude polar orbits

Attitude Control

The primary stabilization loop of the Tug vehicle is the attitude control loop which is closed by the flight program in the central computer The control law requires vehicle turning rates and accelerations and commanded and actual vehicle attitudes, with respect to the prescribed reference frame, as inputs Attitude error commands are issued to the engine actuators through the vehicle control system to effect the control function

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Limits are applied to the rate of change of the commanded attitude, the commanded attitude error magnitude, and the rate at which the commanded attitude error may change Vehicle angular rates are thereby maintained within safe limits. The control function is required throughout the mission although the frequency of control computations is higher during boost than during orbit.

During the boost period, when control is provided by the main engine, significant control authority with relatively fast vehicle response is available Therefore, a high iteration rate for the control computations is required During the orbital phase, control is maintained by a reaction jet system with limited control authority Thus, since the response of this system is slow, a relatively slow iteration rate for control computations is adequate

Sequencing

The flight program functional requirements include sequencing of the discrete vehicle events. A limited number of discrete sequencing requirements are satisfied by use of the discrete outputs of the central computer The flight program itself must sequence into the different phases in response to interrupts and discrete inputs from the vehicle. These vehicle interrupts and discrete inputs signal the occurrence of specific mission events.

The vehicle sequencing requirements are based on the occurrence of specific mission events Therefore, the vehicle sequencing requirements are divided into several distinct series of commands. Each series is referenced to a specified event In this manner, vehicle sequencing is correct in spite of perturbations during previous mission phases

Telemetry

Data are required from the flight program during its operation for real time monitoring of guidance system performance and for detailed post flight evaluation Real time data generally consists of the state vector, error or backup indications, vehicle attitude, and program/vehicle status, mode, sequencing, and timing information Detailed data generally consist of intermediate guidance calculations and hardware information. These data are transmitted to the ground stations through the Tug telemetry system

Command Processing

The Digital Command System (DCS) provides the capability to alter certain specified flight program functions and data upon receipt by the flight program of the proper commands and data from the ground. Some commands will require only a valid mode command for execution while others, such as Navigation Update, require a valid mode command and appropriate data for execution Through use of the command capability, several preplanned alternate modes can be entered or corrections can be made for certain predefined off-nominal performance situations or vehicle failures through the update and generalized sequencing commands

The flight program first validates the mode and data sequence upon receipt of the command Appropriate data are telemetered to the ground to indicate acceptance and validation of the command If any of several non-allowable conditions exist upon receipt of a command, such as invalid command, out of sequence mode or data, or valid command at a wrong time, the flight program transmits the proper error message to the ground to inform flight controllers of the conditions so that appropriate action may be taken

With the exception of the Targeting Load command and the other commands required to support it, the command capability is only required during the coast phase of the mission

Table 9 5 4-1 presents the Tug Flight Software size and complexity summary

Table 9 5 4-1 Space Tug (Level II) Flight Software Sizing Summary

FUNCTION	INSTRUCTIONS (WORDS)	DATA (WORDS)	COMPLEXITY
EXECUTIVE			
• TASK MANAGEMENT	225	345	1
• INTERRUPT PROCESSING	120	50	1
• DISCRETE PROCESSING	45	26	3
• TIMEKEEPING	94	45	3
• I/O CONTROL	100	650	3
• INITIALIZATION/TERMINATION	900	83	2
• MATH UTILITIES	864	---	.3
• COMMAND DATA POOL	---	1500	---
NAVIGATION			
• NAVIGATION EXECUTIVE	155	51	8
• BOOST NAVIGATION	178	69	8
• COAST NAVIGATION	1238	192	5
• NAVIGATION UPDATE	591	282	.4
• RENDEZVOUS NAVIGATION	2450	406	2
• DOCKING NAVIGATION	1131	317	.2
• IMU ALIGNMENT	2452	822	4
• NAVIGATION UTILITIES	578	125	3
GUIDANCE			
• GUIDANCE EXECUTIVE	83	38	.8
• DOCKING GUIDANCE	1103	279	1
• BURN TERMINAL GUIDANCE	105	37	5
• COAST GUIDANCE	254	53	.75
• BURN GUIDANCE (IGM)	1645	280	.25
• TARGET OPTIMIZATION	3000	160	5
• GUIDANCE PRESETTINGS COMP	200	---	25
• TARGET UPDATE	100	---	.5

Table 9.5.4-1. Space Tug (Level II) Flight Software Sizing Summary (Continued)

FUNCTION	INSTRUCTIONS (WORDS)	DATA (WORDS)	COMPLEXITY
TELEMETRY			
ATTITUDE CONTROL			
• INITIALIZATION	64	30	.75
• UPDATE ATTITUDE	15	3	9
• COMPUTE, TRANSFORM ERRORS	43	11	.9
• BURN CONTROL LAW	233	32	.5
• COAST CONTROL LAW	64	23	6
• CONTROL OUTPUTS	106	23	1.0
SEQUENCING			
• NORMAL COMMAND ISSUANCE	224	21	6
• ERROR PROCESSING	195	28	.4
• NOMINAL PROCESSING TABLE	51	9	4
• ALTERNATE TABLE PROCESSING	47	11	.4
• DATA TABLES	---	1700	---
• BLOCK MAINTENANCE	169	30	5
• RECORDER CONTROL	161	34	75
• STATION VECTORS (10)	---	30	---
UPLINK PROCESSING			
• READ INPUT	211	34	.4
• MESSAGE PROCESSING	154	35	6
• MESSAGE ACKNOWLEDGEMENT	53	6	9
• ERROR PROCESSOR	66	10	75
• DATA OUTPUT	38	6	1 0
• DATA BUFFER	---	100	---
• FUNCTION PROCESSING	1300	100	.25
IMU PROCESSING			
• READ INPUT DATA	50	12	1.0
• FILTER AND CONVERT DATA	100	108	5
• BODY-TO-INERTIAL TRANSFORMATION	50	9	4
• IMU REDUNDANCY MGT	800	60	2

9 5 5 GROUND DATA SYSTEM

The central computer within the Tug control center, through its software, is the focal point for the entire mission support operation The computer must support a myriad of capabilities - examples of which are listed below

- Mission Program Development and Test
- System Simulation
- Scientific Computation
- Training of Flight Controllers
- Real-Time Support of Tug Mission
- Schedule and Control Jobshop Work

Because of the criticality of the Central Computer to the overall operation, it is essential that the computer selected be capable of handling all planned functions in an orderly fashion and also provide sufficient growth capability to support changing requirements as the Tug program matures The growth factor is particularly significant in view of the fact that the RTCC software required for support of the Apollo Program expanded by approximately 50 percent during that program As a result, the central computer became marginal, in some instances, in its ability to perform the burden of work placed on it

9 5 5 1 Computer Selection Considerations

The principal driving factors in the selection of a computer system are the memory capacity of the computer and its Central Processing Unit (CPU) capabilities. Additional factors to be considered are peripheral device capabilities and the ability to interface with special devices required in the Tug control center The following paragraphs discuss the primary factors of memory capacity and CPU capabilities as they relate to the Tug control center central computer

9 5 5 1 1 Memory Capacity

The total size of the system software required to support the Tug mission is 728,114 words However, it is not necessary for the entire program to continuously reside in main memory Through a proper structuring of the software system, a significant amount of the program can be placed on auxiliary storage devices to be read into main memory when required This technique will reduce the demand for core-resident programs and, therefore, reduce the main memory capacity requirements, however, the use of auxiliary storage will require significant input/output operations which may affect the ability of the system to satisfy response time requirements

In selection of the computer, a maximum case main memory requirement must be established Through analysis of the software functional requirements, it was determined that the maximum memory utilization case for the Tug control center would occur when the executive, vehicle system, and mission profile modules of the mission program software were required simultaneously

As shown in Table 9 5.5-1, such a combination of software would require approximately 348,450 words of main memory Vehicle system software consists of the downlink processing module and the uplink processing module, which collectively require 128,350 words of storage, if all vehicle system software were simultaneously in main memory Worst case analysis has shown

that the maximum simultaneous requirement, however, is only 65 percent of the total vehicle software This reduces the actual storage load to 83,427 words

The mission profile module total word requirement is 159,790 words, as shown on Table 9 5.3-8, of which 34.8 percent is the maximum simultaneous requirement This adds 55,607 words to the total simultaneous memory requirement.

The control software cosists of the executive system module and the control center support module, which collectively require 256,134 words of storage The maximum simultaneous requirement is 81 76 percent of the total control software This adds 209,415 words to the total simultaneous memory requirements.

Table 9.5.5-1 Co-Resident Summary Requirements

FUNCTION	WORDS
CONTROL	209, 415
VEHICLE SYSTEM	83,427
MISSION PROFILE	55,607
TOTAL	348,449
TOTAL + GROWTH FACTOR	696,898

9.5.5 1 2 CPU Utilization

CPU capability is defined to be the number of operations a computer can perform within a one second interval In selection of the central computer, it is required that the computer have sufficient computational capability to perform all defined functions within the specified time constraints As in the case of memory capacity, CPU growth capability must also exist for additional computational requirements as the Tug Program matures

Within the Tug control center, the principal factors which directly affect the CPU requirements are

- Software execution rates
- Input/output requirements
- Response times to user requests

The determination of CPU execution rates for a proposed computer system is a detailed effort requiring the use of extensive modeling techniques These modeling techniques require a detailed knowledge of software module content and frequency of operation The preliminary nature of software module definition contained in this study precludes the use of such techniques and, therefore, an alternate approach was taken.

The functional similarities between the RTCC, JPL, and TOC requirements provide a means whereby an analysis of extending system CPU utilization can

establish a baseline for CPU requirements Because the RTCC is a "man rated", real-time system, its CPU utilization was selected as an upper bound A minimum bound was established from the JPL operation, which is a non-man rated, non-real-time system

Control Center Computer execution rates were then assumed to be greater than the JPL operation and less than the RTCC Through comparative statistics, it was established that the maximum case CPU utilization would require 20 percent less than the RTCC maximum Table 9 5 5-2 documents the statistics for the subject control centers

The 75 percent maximum utilization for the TOC when applied to the 360/75 Model J, results in a maximum CPU utilization of 3 85 x 10^6 operations/second required of the Control Center central computer

Table 9 5.5-2. Control Center CPU Utilization

CONTROL CENTER*	% CPU UTILIZATION		
	MIN	MAX	AVG
RTCC (APOLLO)	40	95	50
JPL	10	60	12-15
TOC (PROJECTED)	30	75	40

* Computer System IBM 360/75, Model J
Cycle Time - 195 Nanoseconds, 5 128 x 10^6 Operations/Second

9 5 5 1 3 Growth Considerations

As has been stated previously, growth capability in both memory capacity and CPU capability must be considered in computer selection IBM's previous experience on similar ground control centers (RTCC and JPL) indicate that growth potential in both areas should be approximately 50 percent to satisfy requirements Failure to provide for this growth can severely restrict the ability of the IUS control center to expand with the increasing requirements placed upon it A major objective in selecting the central computer should be to provide for orderly growth in capability throughout the lifetime of the center

9 5 5 2 Candidate Computers and Selection

As was developed previously, the main memory capacity must be a minimum of 348,449 words to handle maximum case memory requirements, and the CPU capability must provide 3 85 x 10^6 operations/second An additional 100 percent increase in these capabilities to provide the desired growth capacity yields the following characteristics the candidate computers must satisfy

- Memory capacity - 696,898
- CPU capability - 7 7 million operations/second

The candidate computers, within the IBM/370 line, which should be considered for the ground control center application with the growth capability provided, are shown in Table 9 5 5-3

Table 9 5 5-3 Candidate Computers

THE LIST OF CANDIDATE COMPUTER SYSTEMS (IN ASCENDING ORDER OF INSTALLED COST) MEETING OR EXCEEDING THE MAIN MEMORY AND CPU CRITERIA IS

	SYSTEM	MODEL	INSTALLED COST	YEARLY MAINTENANCE	REQ'D AREA	MEMORY (MEGA WORDS)	CPU SPEED (MEGA OPS/SEC)
1	3158	MP5	6205376	134458	3024	79	8 70
2	3158	MP6	6711376	138795	3024	1 05	8.70
3	3168	MP3	9811661	276393	3024	79	12 50
4	3168	MP4	10317601	281730	3024	1 05	12 50
5	3168	MP5	10931201	291071	3024	1 31	12 50
6	3168	MP6	11437201	295408	3024	1 57	12 50
7	3168	MP7	11943201	299745	3024	1 84	12 50
8	3168	MP8	12449201	304081	3024	2 10	12 50

From the preliminary analysis conducted in this study, the 370/158-MP6 appears to be the minimum cost computer which provides the desired growth potential

Prior to actual selection of a computer for the ground control center for the Tug missions, an extensive modeling study should be conducted This study should utilize the system requirements and software definition and develop a detailed model of the control center computer system From this model, detailed statistics can be gathered regarding such items as main memory requirements, CPU utilization, auxiliary storage utilization, and system response times All of these data can then be utilized to determine the most cost-effective computer system for the control center

9 6 PHYSICAL PLANT

It has been assumed for the purposes of this study that no existing facilities will be utilized This requires that a separate physical plant be designed to house the flight control, flight support, data system, and staff equipment areas required to support the operation functions

The only variable which controls a portion of the physical plant design is the number of consoles required by the flight control personnel and the flight support personnel This parameter varies as a function of the operational philosophy and data display requirements

Figure 9.6 0-1 presents a representative floor plan for a typical concrete block, slab foundation structure, 114 feet by 90 feet, to house the flight control functions It is assumed that the government will contract the construction of the physical plant and therefore, cost to the government will be in two phases (1) those costs involved in administering and overseeing the contract during the period of its execution and (2) the procurement cost of the completed building

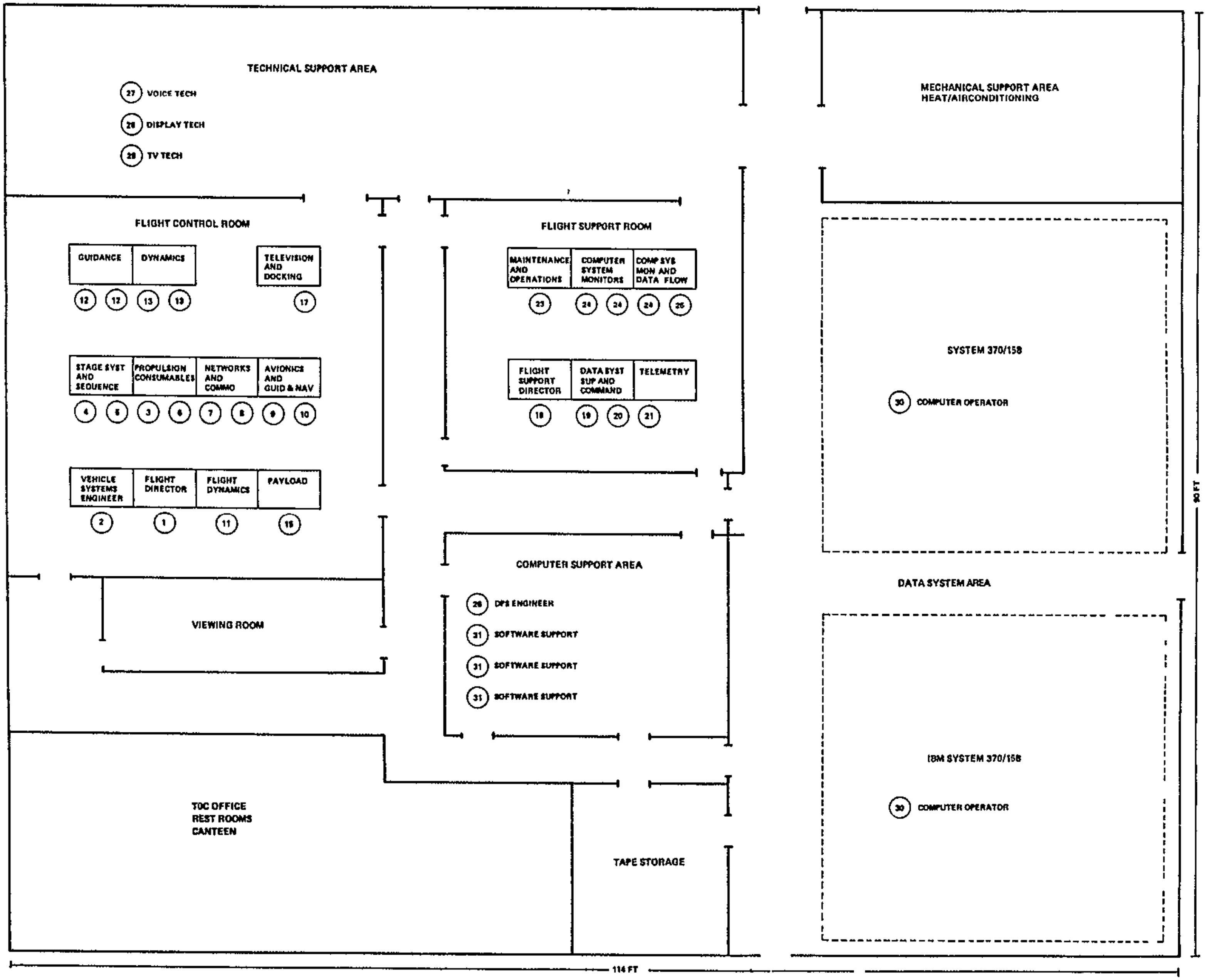


Figure 9 6.0-1 Representative Floor Plan and Staff Stations

Procurement costs are estimated on the following basis

Raised floor construction - areas requiring subfloor cabling, air conditioning, etc , will cost $50.00 per square foot to construct

Ordinary floor construction cost $35.00 per square foot to construct

Figure 9.6 0-1 depicts a representative floor plan with sufficient capacity for the personnel and equipment specified in this study. Total area for this particular TOC layout is 9,836 square feet of which the following allocation of space is tabularized in Table 9.6 0-1.

Table 9 6.0-1. TOC Area Space Allocation

TOC AREA	SQUARE FEET
Flight Control Room	1100
Viewing Room	243
Flight Support Room	500
Computer Support Area	594
Tape Storage	255
Office, Restrooms, Canteen	1080
Technical Support Area	1296
Mechanical Support Area	612
Data System Area	3024
Hall/Lobby	1132
TOTAL	9836

The prime considerations in developing this configuration were separation of functions, equipment space requirements, and operations staff positions locations.

Space allocation for display consoles in the Flight Control Room and Flight Support Room are based on a standard 6 x 4 foot console with a six foot separation between console rows for chair, bookcase and passage Console arrangement is based on operational function and console operator duty This orderly arrangement of consoles groups teams with similar responsibilities and consoles with supervisory and summary displays. This provides efficient mission support during high and low mission phase activity. It is of particular significance during low activity phases where manning is minimal Operational positions that are manned are adjacent permitting efficient monitoring all of active Tug vehicle systems during this period. Consoles in the Flight Control and Support Rooms face the Technical Support Area. This arrangement accommodates the utilization of special large screen displays should this be desired. The space allocated in the Data Systems Area is comparable to current space requirements for all equipment associated with a dual IBM System 370/158.

9 7 COST ESTIMATES

The two key elements to the cost estimate methodology are the involvement matrix and the cost analysis programs The involvement matrix is constructed by analyzing the mission timeline modules and placing each subfunction within each timeline module on the vertical axis of the involvement matrix, and by analyzing the support characteristics of the operational elements on the horizontal axis of the matrix The operational autonomy was then used as a guide for establishing the involvement of a mission timeline subfunction with a support element The involvement matrix thus establishes a relationship between Space Tug missions and the support requirements of the Space Tug missions, which is then used as a data base for analyzing these relationships

The major output from the involvement matrices are support requirements This is a summary of the impact the mission structure has upon the ground support structure

In parallel with the manipulation of the involvement matrices, reference missions were constructed by sequencing mission modules into modular timelines These modular timelines are utilized in the cost analysis programs to establish shift density, overlap of modules and overlap of missions when compared to the associated traffic model in the cost analysis programs The cost analysis programs accept inputs from the traffic model, support requirements, and the modular timelines, then produce a detail printout of DDT&E expenses and recurring cost expenses Figure 9 7 0-1 illustrates the Tug methodology.

9 7 1 Involvement Matrix

The involvement matrix is a 277 row by 137 column matrix which defines the involvement of the operational elements with the operational functions in the covering set of mission operations requirements The involvement matrix provides a method of quantifying the effects of variations in support technique and variations in mission operations functions. The difference between the number of relations involved in Level II autonomy support and in Level III autonomy support provides a direct process of quantifying the support element requirements During the study progress, it has been demonstrated that the involvement matrix is a valuable tool for the quantification of support elements and, therefore, can be utilized to establish a comparative relationship between cost and autonomy level Figure 9 7 1-1 presents the involvement matrix. The 137 operational elements are listed across the top of the matrix The 277 mission operational functions and subfunctions are listed vertically.

9 7 1 1 Autonomy Level Differential

Figure 9 7 1-2 shows a typical set of Involvement Matrices, one for Level III autonomy, one for Level II autonomy, with the involvements indicated by a "1" entry in the matrix cells and no involvement by a "0" in the matrix cells By analysis of the differences in involvement, the support requirements may be ascertained It will be noted that the involvement matrix is merely a convenient organization tool for the exploration of inter-related factors The validity of the matrix lies in the effort expended by knowledgeable flight control systems engineers in analyzing the operations

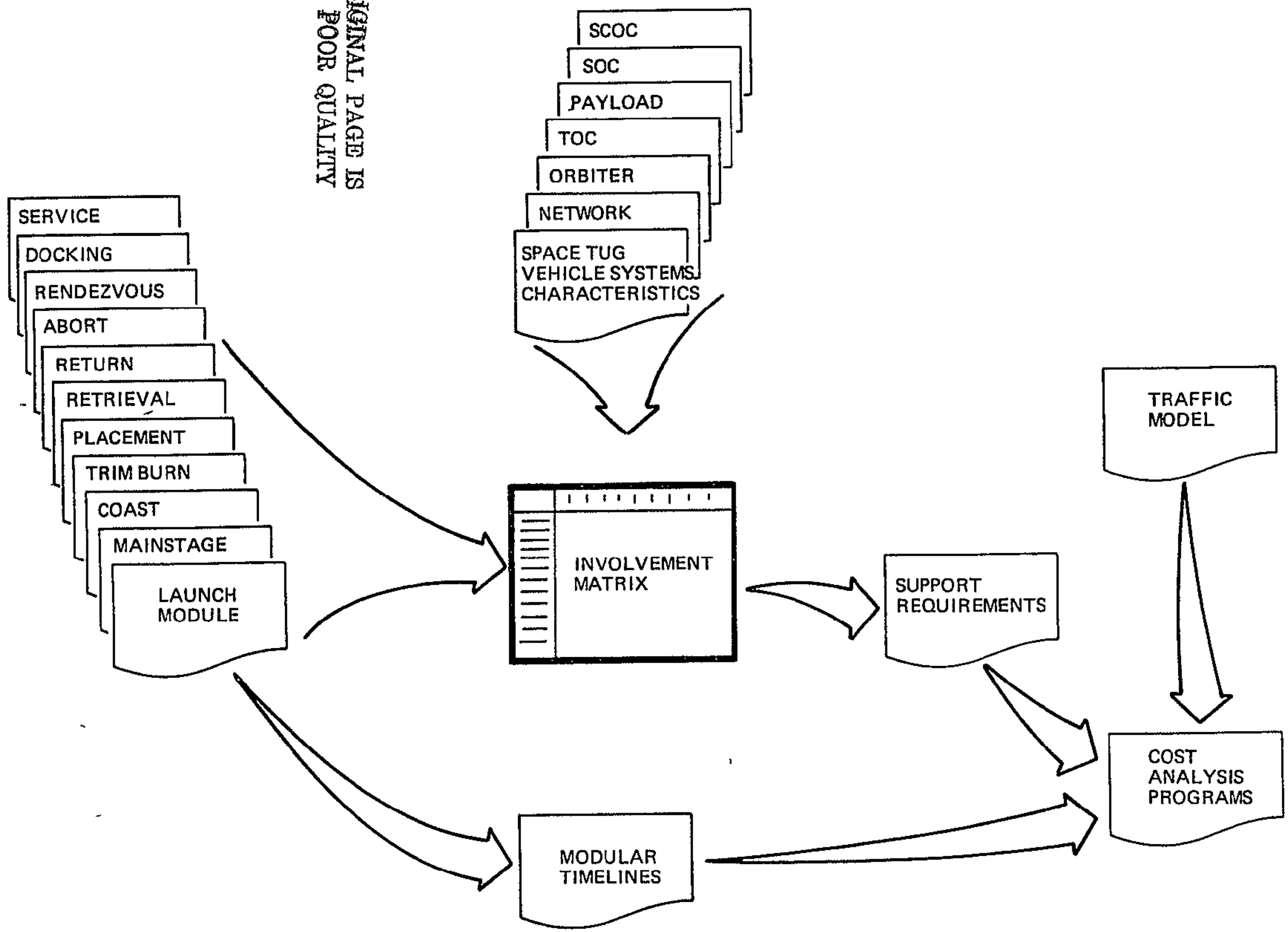


Figure 9.7.0-1 Space Tug Cost Estimates Methodology

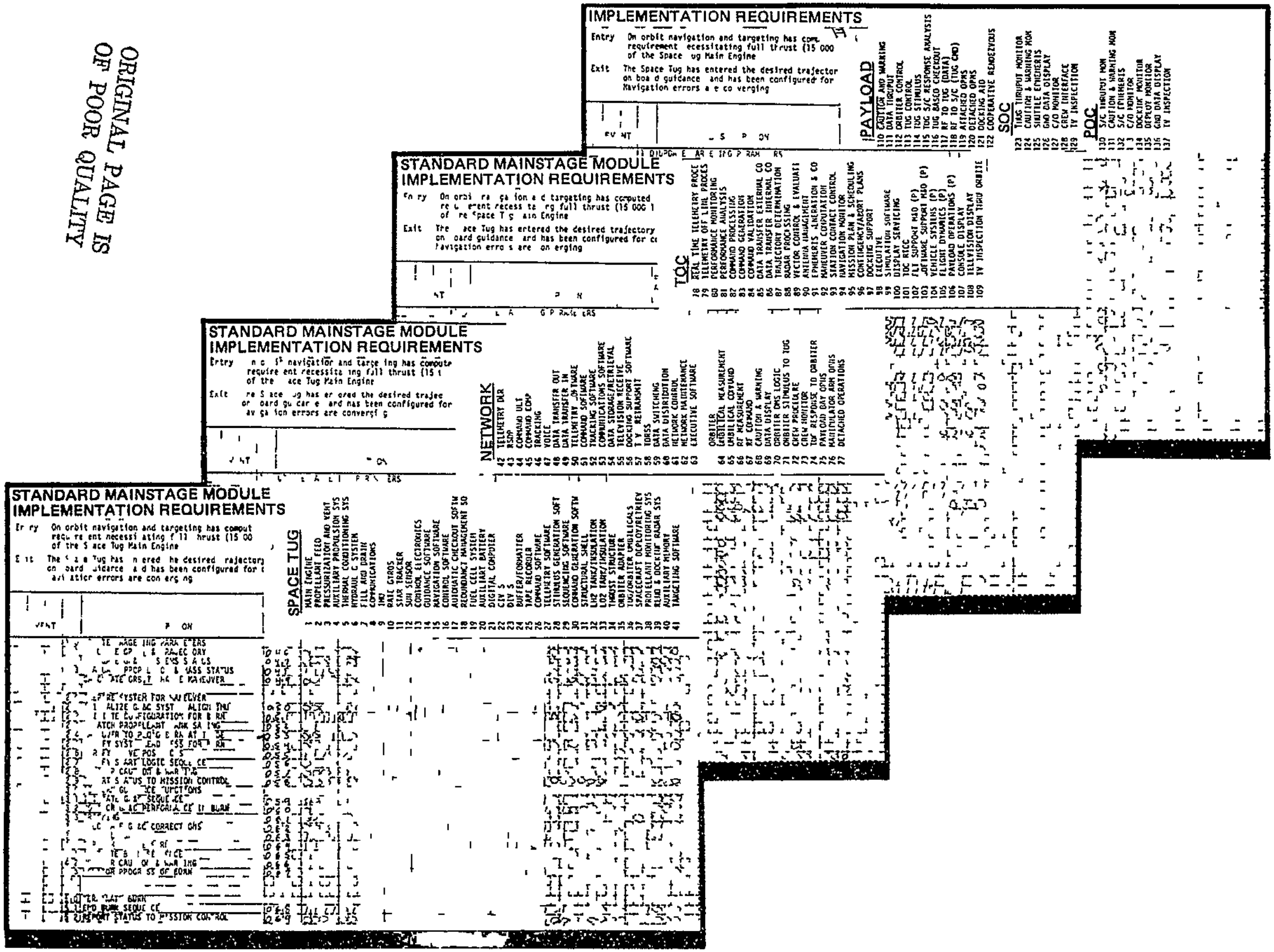


Figure 9 7 1-1. Involvement Matrix

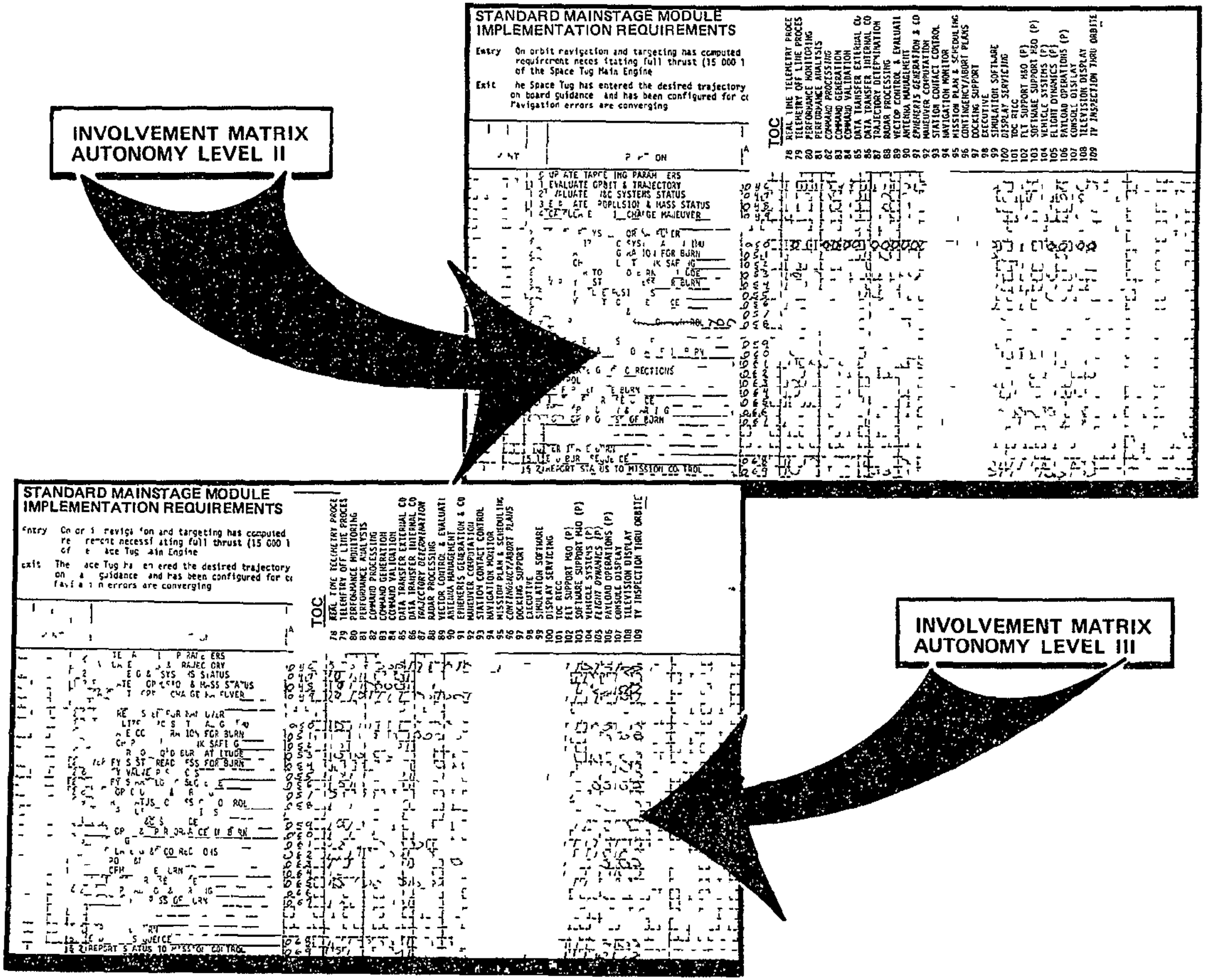


Figure 9 7 1-2 Autonomy Level Differentiation

9 7 1 2 Autonomy Level Differentiation Example

Figure 9 7 1-3 highlights one line of entries for control center involvement That line is relative to the initialization of guidance, navigation and control systems and the alignment of the inertial measuring unit prior to a main stage burn It will be noted that there are four differences (additions) between Level II and Level III implementations Those four differences are in the requirement for 1) command process, 2) command generation, 3) command validation, and 4) data transfer outside the Tug operations center All of the foregoing are required to provide a ground command interface with the Tug vehicle The significance in that partial row (Level II) is that the onboard system is not entirely responsible for functions required to initialize the guidance, navigation and control system and can thus rely upon the ground for some level of assistance in accomplishing those funcions In turn, flight software may be reduced, at the expense of increasing ground software and ground manning requirements Costs can then be associated with each of the two related functions and the cost optimal implementation selected.

9 7 1 3 Cost Analysis Programs

Fifteen cost analysis programs have been used to investigate various aspects of the support element cost Figure 9 7 1-4 presents the flow of logic as implemented in the analytical software which creates the total development costs and total recurring costs for an operational concept The inputs to and the outputs from the operations are illustrated The software active during the various processes are displayed by their mnemonic designators placed in the elliptical bubbles near the operations Cost output information, that is, printouts available of the programs, are enclosed in rectangular boxes with either the letter D or the letter R entered in the box, indicating the final utilization of the derived cost in either the DDT&E summation or the recurring cost summation, or both A sixteenth program, which analyzes the alternate concepts of mission operations, was utilized in the generation of prior study results

9 7.2 DDT&E Costs - Level II Space Tug

First estimates of DDT&E costs have been derived for the Level II Tug, by using the cost analysis programs presented in a previous section These estimates encompass all "deliverable" end items in the Tug program, but do not contain cost elements which have intermediate, or planning type outputs The cost analysis programs account for 90% of the DDT&E expenses A detailed examination of the Work Breakdown Structure (WBS) presented in Volume V will identify the elements not priced by the cost analysis programs

Figure 9 7.2-1 presents the Ground Software DDT&E cost estimate

Figure 9 7 2-2 presents the Flight Software DDT&E cost estimate for the flight software

Figure 9 7 2-3 presents the Data System DDT&E costs.

The operational console hardware is tabulated in Table 9 7.2-1

Figure 9 7 2-4 represents the physical plant DDT&E costs.

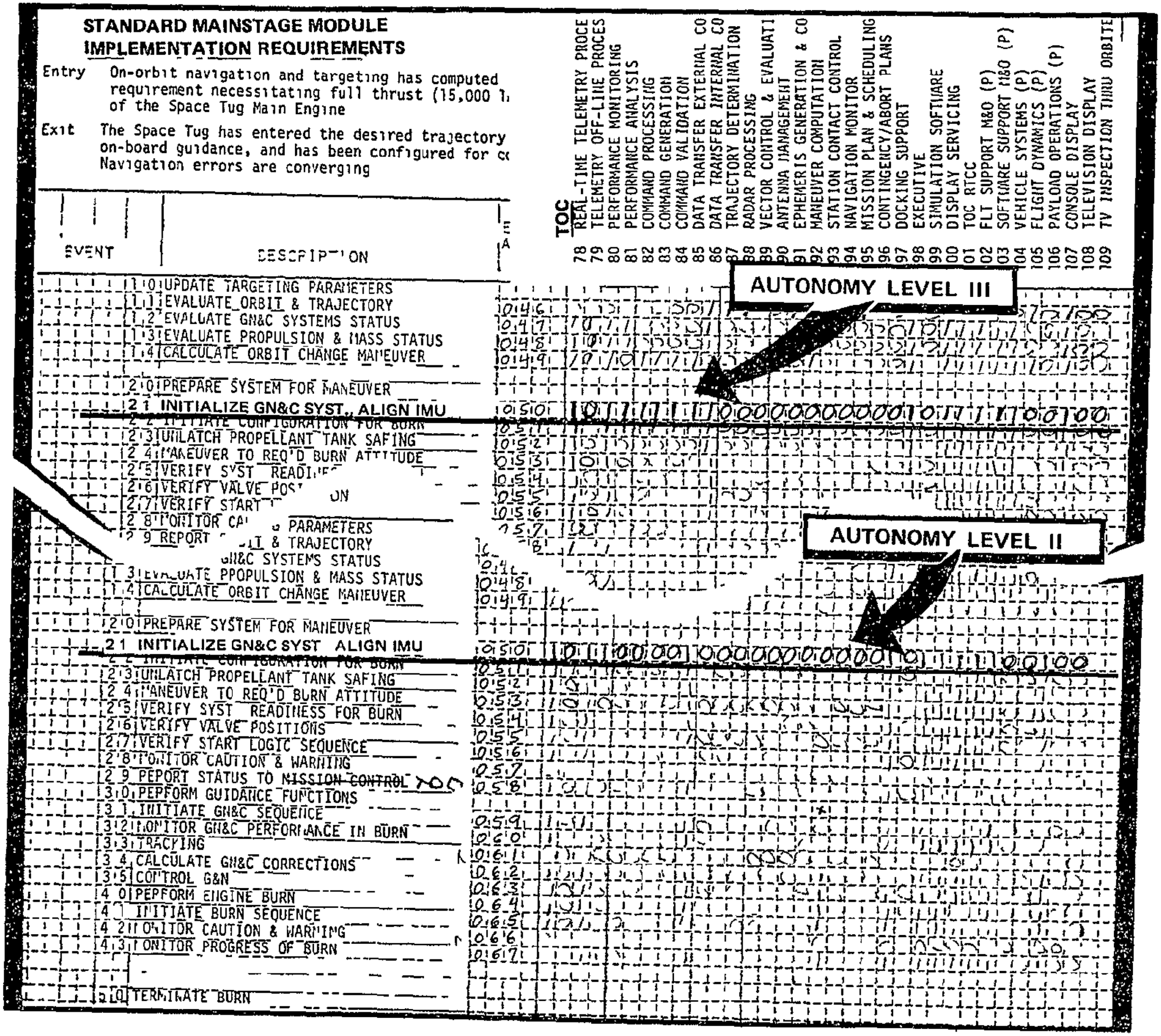


Figure 9 7.1-3 Autonomy Level Differentiation

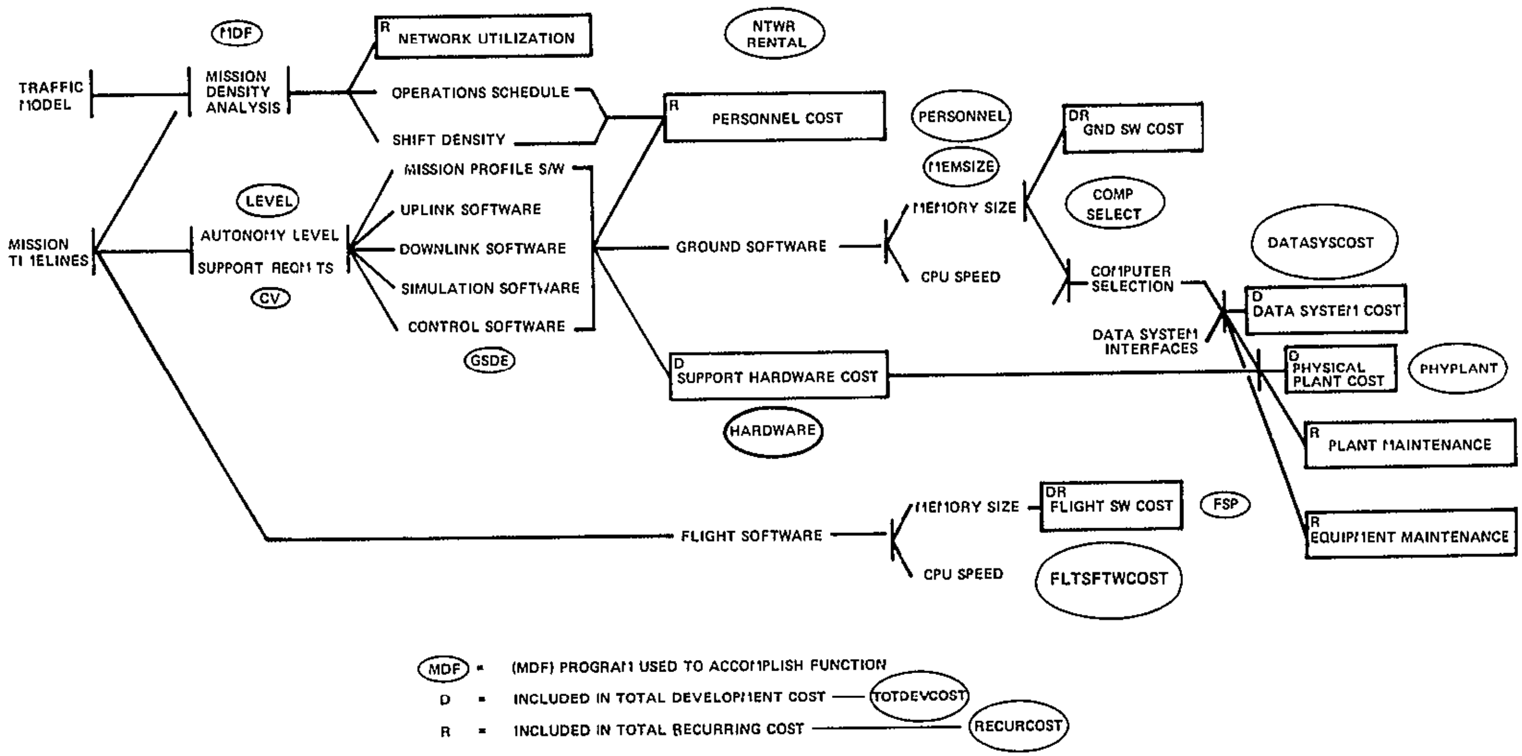
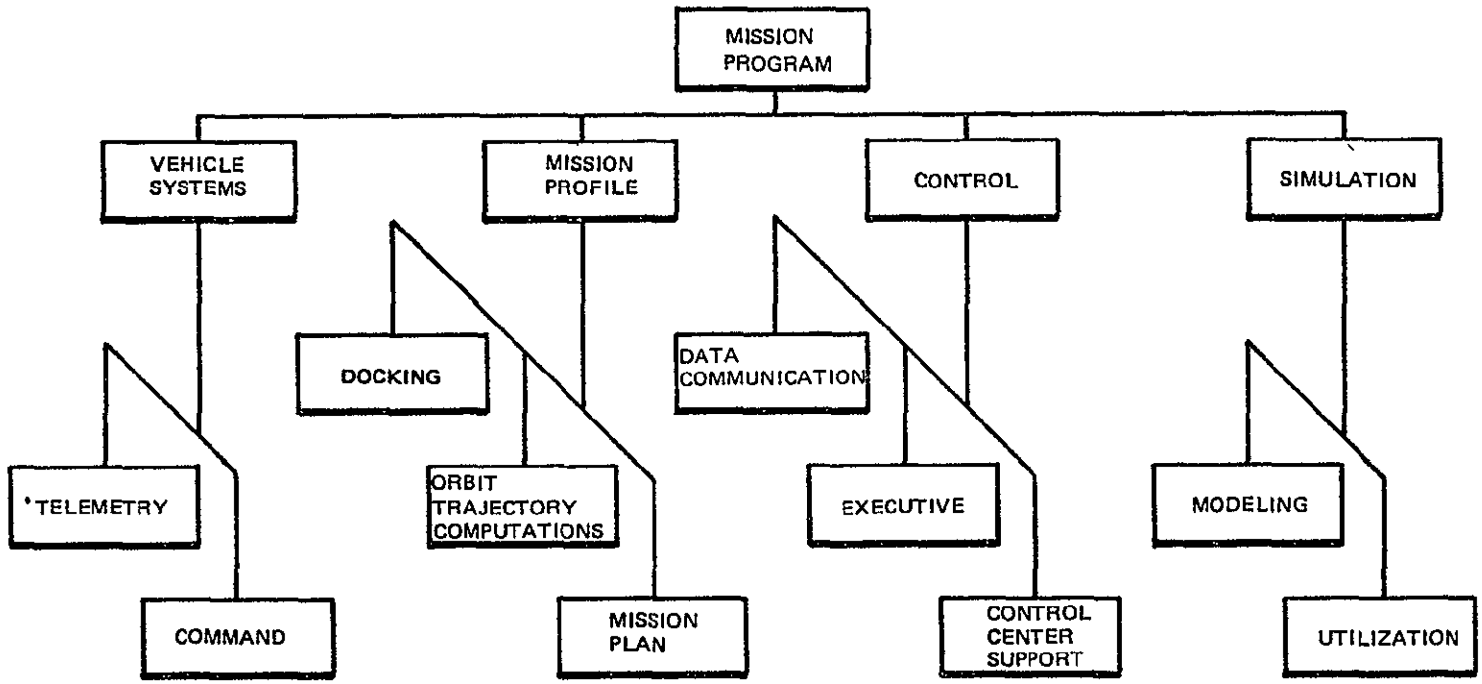


Figure 9 7 1-4 Cost Analysis Programs

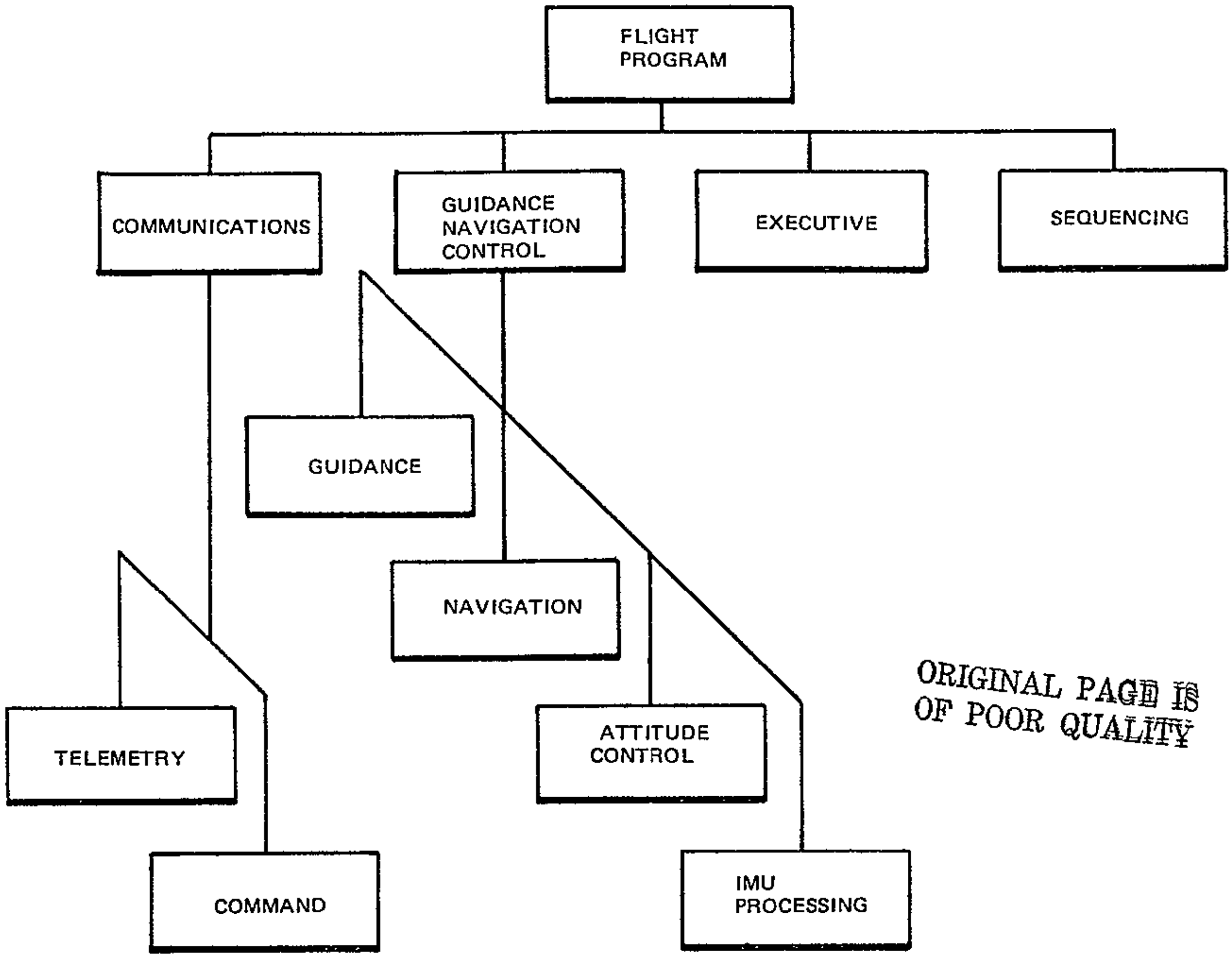


THE CONSTANTS USED IN COMPUTING GND SFTWR COSTS BY THIS FUNCTION ARE

1) *WORKING DAYS/MONTHS* = 21
2) *COMPUTER WORDS/INSTRUCTION* = 1
3) *PROGRAMMER PRODUCTIVITY (INST LINES/DAY)* = 14
4) *COMPUTER WORDS/DATA* = 4
5) *PROGRAMMER PRODUCTIVITY (DATA LINES/DAY)* = 30

PROGRAM	*INSTRUCTION SIZE (WORDS)*	*INSTRUCTION COST (DOLLARS)*	*DATA SIZE (WORDS)*	*DATA COST (D)*	*COMPLEXITY FACTOR*	*TOTAL (D)*
DOWNLINK PROCESSING	68190	927755	12540	19905	1 00	947660
UPLINK PROCESSING	32980	448707	14640	23238	1 00	471946
MISSION PROFILE	109760	1991111	50030	79413	.75	2070524
EXECUTIVE	210900	5738776	29304	46514	.50	5785290
CONTROL CENTER SUPPORT	12690	345306	3240	5143	50	350449
DATA COMMUNICATIONS	0	0	0	0	.50	0
SIMULATION SYSTEM	136800	2481633	47040	74667	75	2556299
TOTALS		11933288		248879		12182167

Figure 9 7 2-1 Ground Software DDT&E Costs

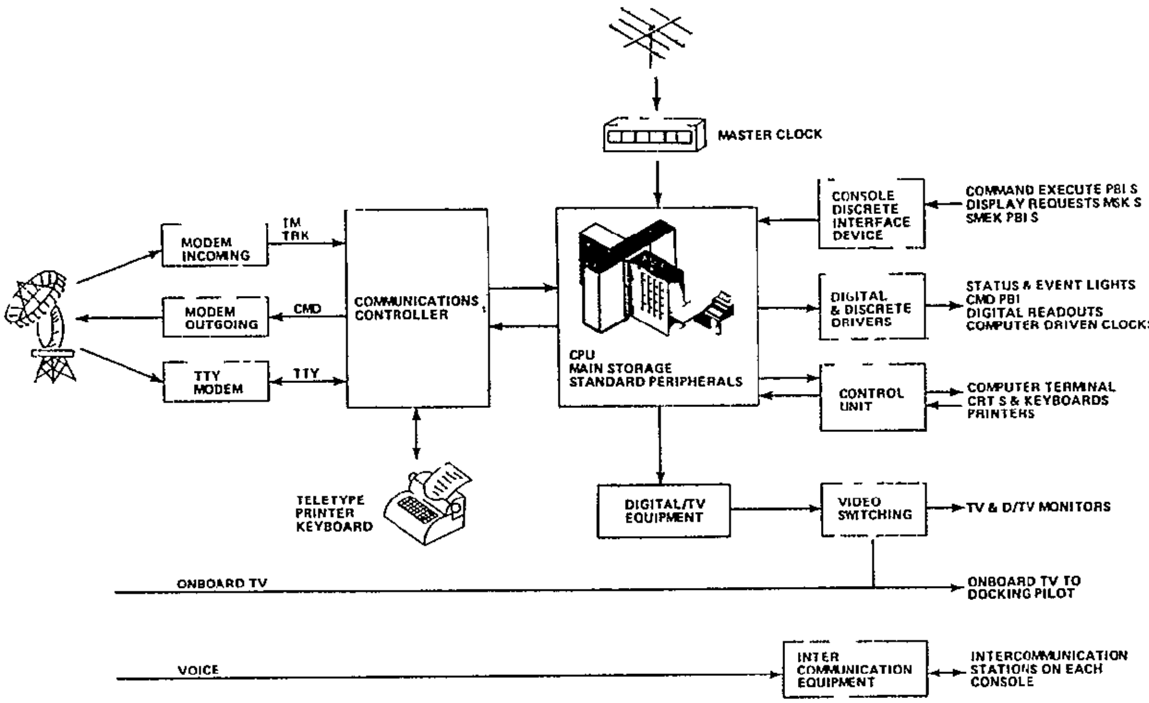


THE CONSTANTS USED IN COMPUTING FLT SFTWR COSTS BY THIS FUNCTION ARE

1) *WORKING DAYS/MONTH* = 21
2) *COMPUTER WORDS/INSTRUCTION* = 1
3) *PROGRAMMER PRODUCTIVITY (INST LINES/DAY)* = 6 9
4) *COMPUTER WORDS/DATA* = 4
5) *PROGRAMMER PRODUCTIVITY (DATA LINES/DAY)* = 30

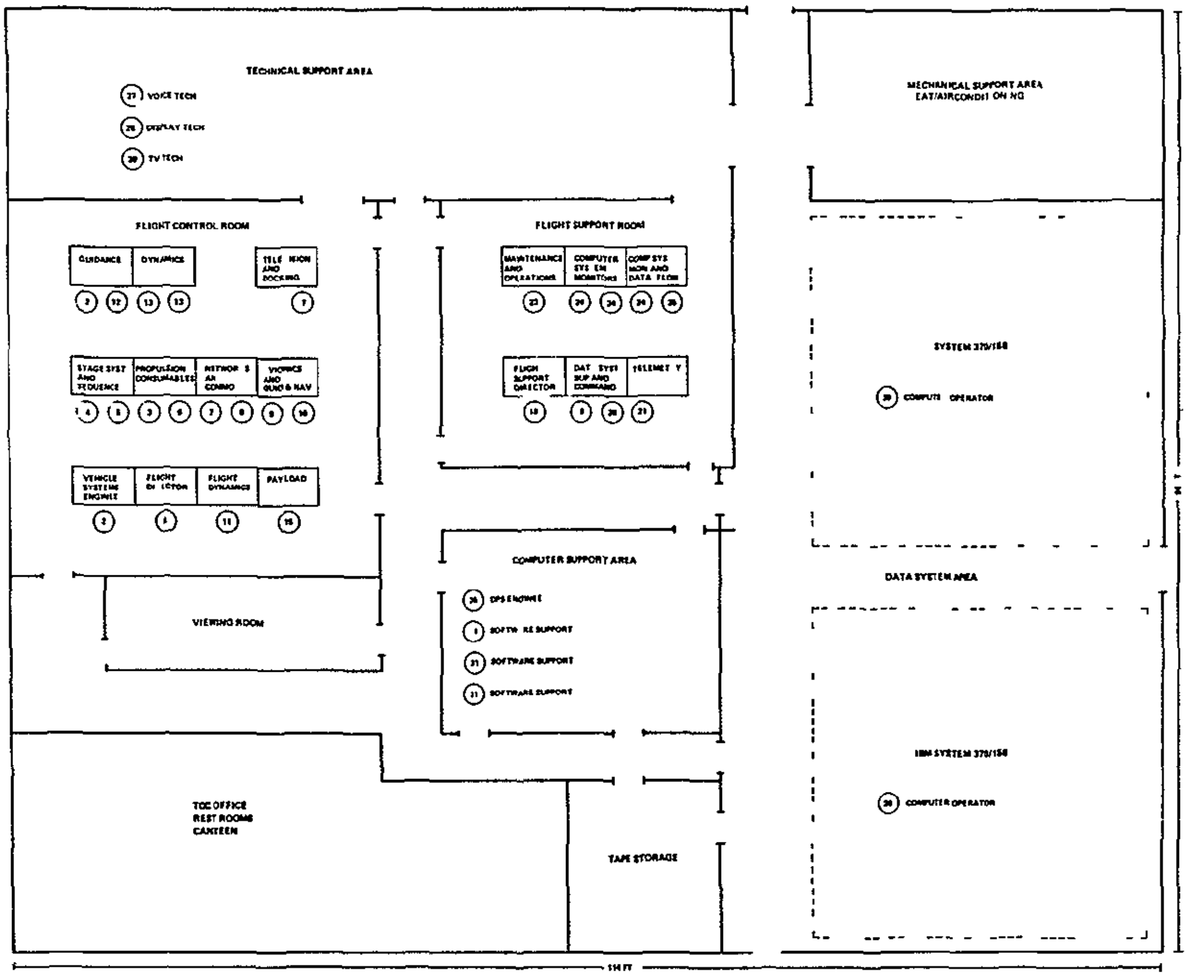
PROGRAM	*INSTRUCTION SIZE (WORDS)*	*INSTRUCTION COST (DOLLARS)*	*DATA SIZE (WORDS)*	*DATA COST (D)*	*TOTAL (D)*
DOWNLINK PROCESSING	330	34632	94	339	34971
UPLINK PROCESSING	1822	386577	291	1049	387626
EXECUTIVE	2348	728572	2699	9725	738297
SEQUENCING	517	69296	1769	6374	75670
GUID ,NAV AND CNTL	16788	3809795	3422	12330	3822125
TOTALS		5028872		29816	5058689

Figure 9 7 2-2 Flight Software DDT&E Costs




```
DATASYS COST
ENTER THE UNIT COST (IN DOLLARS) FOR EACH
OF THE FOLLOWING ELEMENTS
        MASTER CLOCK
        ⎕
             44560
        NTWK  TERMINAL EQUIP.
        ⎕
             20900
        TTY PRINTER KEYBOARD
        ⎕
             3172
        INTERCOM EQUIP.
        ⎕
             230000
        VIDEO SWITCH
        ⎕
             5610
        DATA SYSTEM COST
              ITEM               COST
        3158 MP5               6205376
        MASTER CLOCK             44560
        NTWK. TERMINAL EQUIP.    20900
        TTY PRINTER KEYBOARD      3172
        INTERCOM EQUIP.         230000
        VIDEO SWITCH              5610
                    TOTAL      6509618
```

Figure 9 7.2-3 TOC Support Hardware DDT&E Costs



TOC AREA	SQ FT	$/SQ FT	COST ($)
FLIGHT CONTROL ROOM	1100	50	55000
FLIGHT SUPPORT ROOM	500	50	30000
DATA SYSTEM AREA	3024	50	151200
VIEWING ROOM	243	35	8505
COMPUTER SUPPORT AREA	594	35	20790
TAPE STORAGE	255	35	8925
OFFICES,RESTROOMS,CANTEEN	1080	35	37800
TECHNICAL SUPPORT AREA	1296	35	45360
MECHANICAL SUPPORT AREA	612	35	21420
HALL/LOBBY	1132	35	39620
TOTAL	9836		413620

ENTER THE AREAS (IN SQ FT
VIEWING ROOM
□
243
COMPUTER SUPPORT AREA
□
594

TAPE STORAGE
□
255
OFFICES, RESTROOMS, CANTEEN
□
1080
TECH SUPPORT AREA
□
1296

MECH SUPPORT AREA
□
612
HALL/LOBBY
□
1132

Figure 9 7 2-4 Physical Plant DDT&E Costs

Table 9.7.2-1 Consoles and Hardware Costs

Equipment Item	Quantity	Unit Cost	Total Cost
Console	16	4,800	76,800
Communication Panel	27	6,000	162,000
TV Monitor	32	2,000	64,000
Event Monitor	62	8,000	496,000
MED	17	6,400	108,800
Command Panel	9	7,200	64,800
Display Control Panel	16	2,000	32,000
TOTAL			1,004,400

Table 9.7.2-2 summarizes the total DDT&E costs output by the cost analysis programs

Table 9.7.2-2 Total Tug DDT&E Cost Summary

Element	Dollars
Physical Plant	413,620
TOC Software Development	12,182,167
Data System	6,509,618
Operations Staff Equipment	1,004,400
Tug Software Development	5,058,689
TOTAL	25,168,494

9 7 3 Recurring Costs - Level II Space Tug

The recurring costs incurred in orbital operations and mission support are in the main service type costs, since there are no major hardware refurbishments involved. The types of costs included are facility maintenance, ground software update and maintenance, data system maintenance, flight software maintenance, sustaining facilities engineering, sustaining flight control engineering and network rental expenses. Of these tasks, facility maintenance and data system maintenance will be contracted to outside agencies Ground software update and maintenance will be accomplished by the permanently assigned software support team. The sustaining facilities engineering and sustaining flight control engineering personnel will perform all pre-mission preparations, training and conduct of mission operations. Network rental will be charged to the Operations organization on the basis of the number of hours utilized and the type of service rendered. The flight software maintenance tasks are those tasks involved in defining, programming and verifying mission specific deviations from the basic four flight programs. This is largely a manpower expense. Computer time will be provided by the control center computer at no cost.

9 7.3.1 Facility Maintenance

Facility maintenance includes refuse disposal, janitorial services, internal electrical maintenance, internal power and heating maintenance, internal painting, air-conditioning costs, exterior painting, roofing, and parking

lot maintenance Facility maintenance costs commonly are based upon a constant of approximately $1 32 for government installations and $2 00 for industrial installations The cost of facility maintenance is computed from the estimated number of square feet required by the operations and support areas multiplied by $2 00 per square foot This expense is approximately $20,000 per year

9 7 3 2 Ground Software Update and Maintenance

The approach chosen to develop this algorithm divides the software maintenance task into two subtasks The first subtask consists of finding and fixing software problems, supporting system operation, and installing nominal mission-to-mission program enhancements The second subtask consists of adding new functions and performing major modifications to the existing software system

The cost of the former can best be sized as a "level of effort" task Since software problems will probably be discovered throughout the software system, a level of expertise must be maintained through the availability of personnel familiar with every software area The number of personnel required for each area is dependent on the size, complexity, criticality, and level of mission-to-mission changes for the programs therein

The level of effort will decrease as a function of time Saturn Launch Computer Complex data indicates that the number of software problems decreased by more then 50% during the first year of system operation After the first year, the number of problems should continue to decrease but at a much slower rate

The cost of the second subtask is similar to that of new software development Two offsetting attributes of modification/extension work affect this cost The first is that adding new functions to an existing working system is easier than new work due to the existence of well defined, operational interfaces and system services The second attribute applies to modifications

Modifications usually require a significantly greater degree of design and system testing than the number of instructions involved would indicate Modifications in inter-program interfaces can spread through larger parts of the system causing subtle problems which require extensive system testing Given these offsetting factors and assuming a reasonable mixture of the two, we can approximate these costs by using the same cost algorithm as used for new development work

9 7 3 3 Data System Maintenance

Standard rate schedules exist for the maintenance of large-scale computer systems and the associated peripheral gear. For the data systems chosen, the data system maintenance costs are approximately $135,000 per year for the Tug program Maintenance of all other equipment will be a responsibility of the sustaining flight support engineering organization

9 7 3.4 Sustaining TOC Engineering

A certain minimum staff is required to control and support the control of a Tug vehicle That staff is divided into two major groupings--the flight support group (Sustaining Engineering) and the flight control group. There are 30 personnel required to staff the flight support organization on a continuing basis. These people have been costed at $48,000 per man per year

The size of the staff is established by the real-time support requirements However, the staff, during non-mission and non-training periods, is to be utilized to perform mission preparations and maintenance jobs This multiplexing of personnel is cost-effective in that it spreads the productive work load of the permanently assigned personnel more evenly across the operational periods

9 7 3.5 Sustaining Flight Control Engineering

There is a specific minimum staff required to control the Tug vehicle during mission operational periods. For the Tug program, that staff requirement is 30 flight control engineers The flight control organization is a required sustaining engineering staff which may be utilized during non-mission periods in performing preparation tasks, such as training, scheduling, and interface type operations. As with the flight support staff, the spreading of effort across the period of operations is a cost-effective utilization of the flight control staff

9 7 3 6 Network Rental

In order to arrive at a minimum network rental cost, Philco-Ford designed a system for the transmission of telemetry, command, tracking and television data from six STDN remote sites to the Tug operations control center. This network utilized commercial carrier satellite transmission directly from the ground station to the operations control center Figure 9.7 3-1 presents the network and terminal cost data derived by Philco-Ford.

To implement the network, each of the remote stations requires a line terminal installation, which creates a recurrring cost of $31,700 per month. The line terminal equipment at the remote stations feed commercially available common carrier single-sideband data links at a composite leased cost of $284,830 per month The leased lines are demultiplexed at the operations center by three line-terminal stations.

It is assumed that no costs will be incurred to rent the ground station equipment itself, that is, the data being fed to the line terminals at the STDN sites are supplied free of charge to the Tug program by GSFC It is also assumed that the terminal stations within the operations center are costed as a portion of the network terminal fees and are not part of the network rental computation. The summation of the recurring costs of network leasing per month and the STDN site stations per month are $475,030. To arrive at a minimum cost, the operation of the TDRS system was assumed This reduced the monthly cost of ground station terminal equipment from $190,200 to $31,700

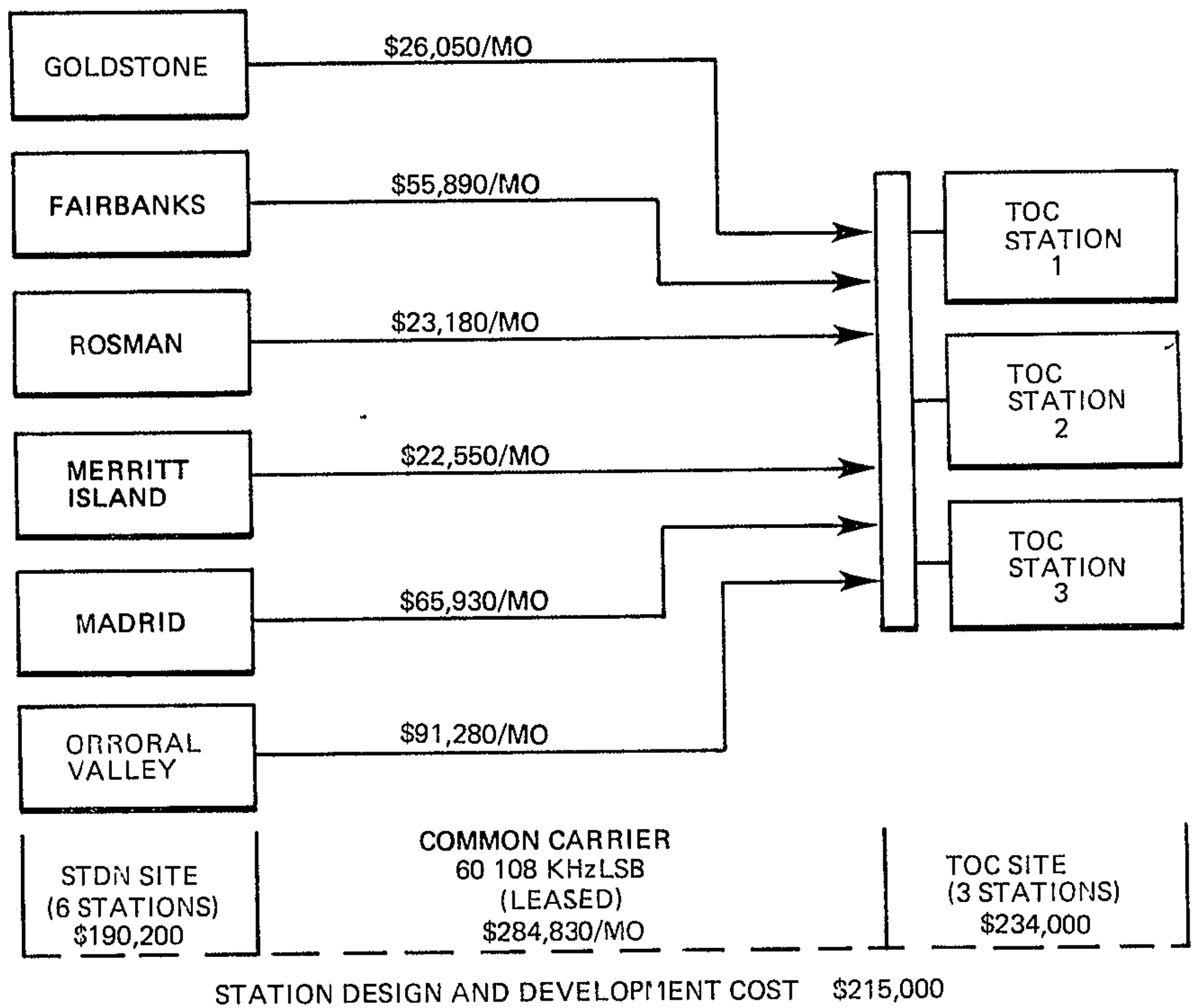


Figure 9 7 3-1 Network and Terminal Cost Data

This was arrived at by assuming the TDRS ground station would be provided with the terminal equipment and a fee equivalent to the leased line cost from the 6 STDN stations would be imposed.

The summation of a single-station line terminal installation and the leased line costs is $316,530. Since these are leased costs, it is assumed that the hourly cost would be equivalent to dividing the summation of leased line cost and ground station recurring cost by the number of hours of operation in a month This gives an hourly rate of $430. Now, the network rental charges will be further based upon the type of service required, since all phases of the missions do not require the entire capability of the leased lines. A further division of the $430 per hour fee was made on the basis of bandwidth requirements The television signal requires 51 kilobits per second, the telemetry signals require 16 kilobits per second, the tracking and command signals require 2 kilobits per second each It was estimated that if a charge were made on the basis of service provided, that charge would be approximately proportional to the bandwidth requirements of the type of signal being processed. On that basis, television was rated at $290 per hour, telemetry was rated at $90 per hour, and command and tracking were each rated at $25 per hour. Those constants were utilized in arriving at the network rental calculations.

The mission density function program within the cost analysis programs calculates the number of hours per year that each of the communications services are required, based upon the launch schedule and mission type established for that year. The baseline year chosen for Tug was 1984

9 7 3.7 Space Tug Software Maintenance

A maintenance and support cost algorithm has been developed for flight software This algorithm assumes that the four baseline programs generated in the DDT&E phase will not be subject to major modifications A major modification, should one be required, is to be costed in accordance with the initial software development algorithm.

The maintenance and support cost algorithm divides the level of effort requirements into manpower required to design the changes, manpower required to program the changes, and manpower required for flight program verification For programs less than 64,000 words (instructions and data) the level of effort is a function of the number of programs being maintained The annual recurring cost for this service is $1.008 million per year for the flight program maintenance efforts.

9.7 3.8 Off-Peak Manpower Utilization

Flight control and flight support are full-time employment for those personnel assigned flight control and flight support duties There will be no multiplexing between operational and non-operational assignments The time during which operations are not in progress will be utilized by the assigned flight control and flight support personnel in preparation, maintenance and other operations related activities. The frequency and complexity of Space Tug missions dictate the assignment of a dedicated staff

9 7 3 9 Summary of Recurring Costs

Table 9 7.3-1 presents a summary of recurring costs

Table 9.7 3-1. Total Tug Recurring Cost Summary

Element	Dollars
Facility Maintenance	19,672
TOC Software Maintenance	1,104,000
Data System Maintenance	134,458
Sustaining TOC Engineering	1,584,000
Sustaining TOC Flt. Control Engineering	1,440,000
Network Rental	204,755
Tug Software Maintenance	1,008,000
TOTAL	5,494,885

9 7 4 Alternative Concepts Cost Data

Figure 9 7.4-1 defines the operational concepts analyzed during the study and the application of the concepts to the IUS and Space Tug Programs

Concept 1, Separate NASA/DoD System, is in accord with the NASA baseline concept and depicts separate NASA and DoD control center development to satisfy their respective requirements In this concept control center hardware, software, manpower and facilities will be the responsibility of each separate agency, however, it does not preclude the potential of cost savings through the development of similar hardware and software

Concept 2, Shared System, defines a single Tug Operations Control Center for both NASA and DoD missions Under this concept each agency would be responsible for all aspects of their respective missions but share common operational elements Two options have been analyzed under this concept, (1) 2A which assumes NASA in a host role in the shared center, and (2) 2B assumes DoD in a host role.

9 7 4 1 Level II Autonomy - Concept Development Cost Comparison

Figure 9 7 4-2 presents a comparison of NASA and DoD expenses for a Level II autonomy Space Tug design under the concepts

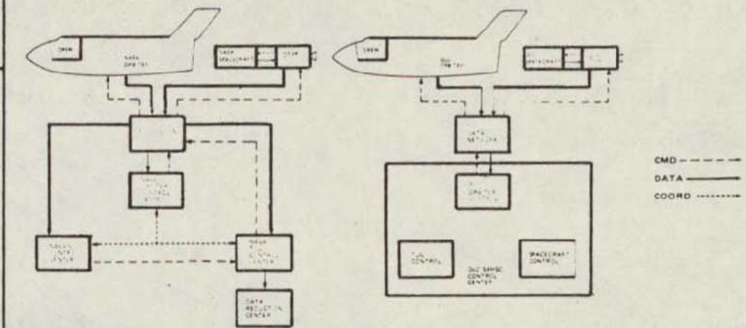
1) Separate and equal NASA and DoD operation
2A) Single facility, NASA owned, DoD tenant
2B) Single facility, DoD owned, NASA tenant

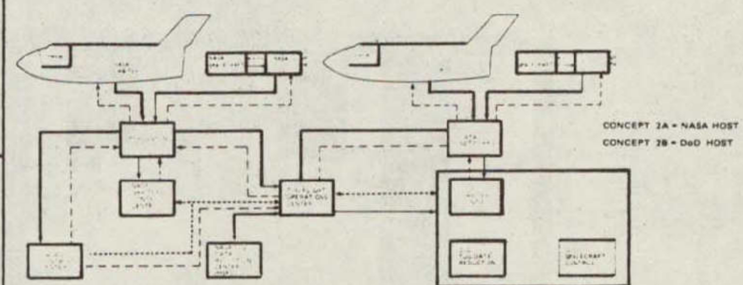
Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and the DoD costs are comparable to NASA costs for similar functions

The shift in costs to increase the host's net outlay in Concepts 2A and 2B does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assests

OPERATIONAL CONCEPTS

	APPLICATION	
	SPACE TUG	IUS
CONCEPT 1 – SEPARATE NASA/DoD SYSTEM	X	X
CONCEPT 2 – SHARED SYSTEM A. NASA HOST/DoD TENANT	X	
B. DoD HOST/NASA TENANT	X	
CONCEPT 3 – DoD SYSTEM (ALL IUS FLIGHTS)		X





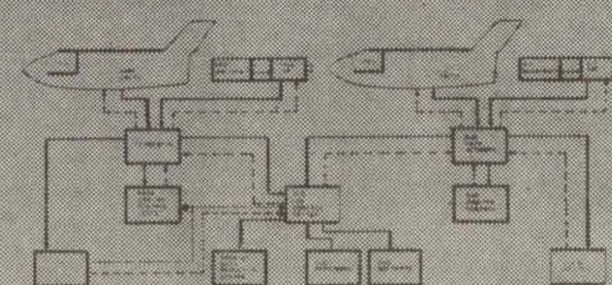
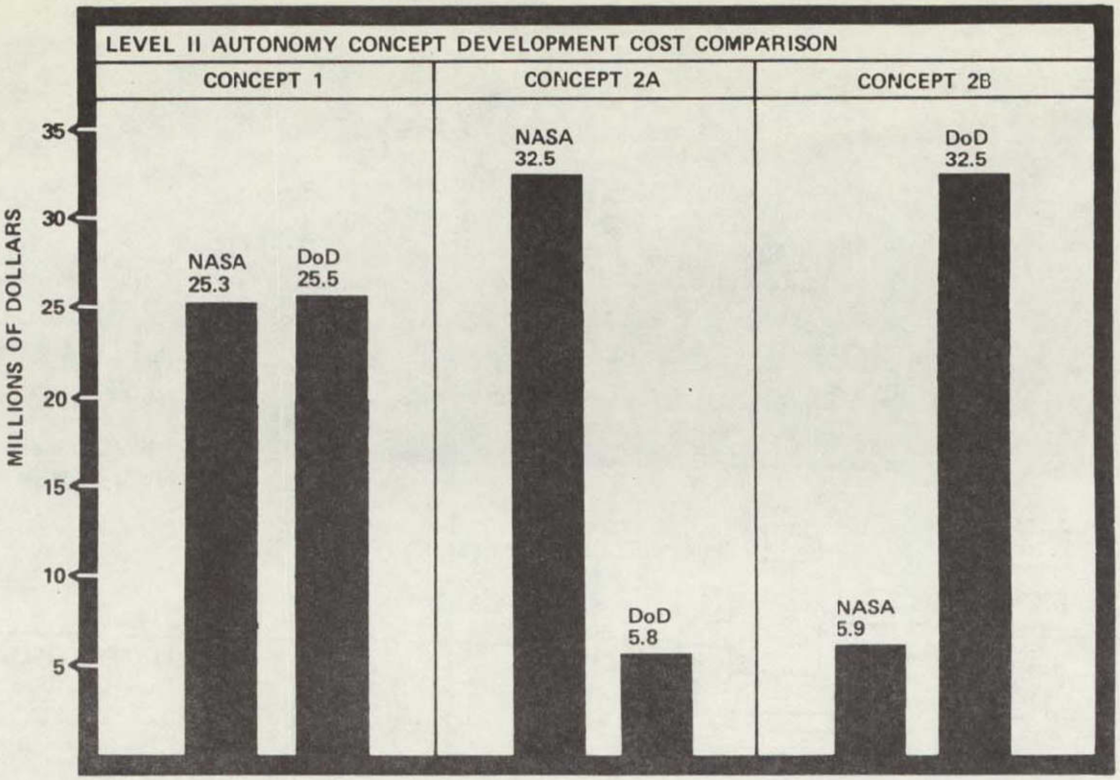


Figure 9.7.4-1. Operational Concepts



TOTAL ALTERNATIVE DEVELOPMENT COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 2A NASA	ALTERNATIVE 2A DOD	ALTERNATIVE 2B NASA	ALTERNATIVE 2B DOD
PHYSICAL PLANT	423620	465982	563414	0	0	563523
TOC SOFTWARE DEVELOPMENT	12262924	12262924	15040932	773051	875605	15040932
DATA SYSTEM	6509618	6509618	9764427	0	0	9764427
OPERATIONS STAFF EQUIPMENT	1120800	1232880	2107104	0	0	2129520
TUG SOFTWARE DEVELOPMENT	5058689	5058689	5058689	5058689	5058689	5058689
TOTALS	25375650	25530092	32534565	5831739	5934294	32557090

Figure 9.7.4-2. Level II Autonomy Concepts Development Cost Comparison

The costs presented update and supercede the figures presented in the Space Tug Baseline Operations Plan (IBM No 74W-0025) dated November, 1974 Cost increases in operational hardware and flight software have been included

9 7 4.2 Level II Autonomy - Concept Annual Recurring Cost Comparison

Figure 9.7 4-3 presents a comparison of NASA and DoD expenses for a Level II autonomy Space Tug design under the concepts

1) Separate and equal NASA and DoD operation
2A) Single facility, NASA owned, DoD tenant
2B) Single facility, DoD owned, NASA tenant

Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and that DoD costs are comparable to NASA costs for similar functions

The shift in costs to increase the host's net outlay in Concepts 2A and 2B does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assets Tenant income and tenant fees paid are indicated.

The costs presented update and supercede the figure presented in the Space Tug Baseline Operations Plan (IBM No. 74W-0025) dated November, 1974

9.7 4 3 Level III Autonomy - Concept Development Cost Comparison

Figure 9.7 4-4 presents a comparison of NASA and DoD expenses for a Level III autonomy Space Tug design under the concepts

1) Separate and equal NASA and DoD operation
2A) Single facility, NASA owned, DoD tenant
2B) Single facility, DoD owned, NASA tenant

Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and that DoD costs are comparable to NASA costs for similar functions

The shift in costs to increase the host's net outlay in Concepts 2A and 2B does not preclude recovery fo some portion from the tenant, but does assume that host will retain all program assets

The costs presented update and supercede the figures presented in the Space Tug Baseline Operations Plan (IBM No. 74W-0025) dated November, 1974. Cost increases in operational hardware and flight software have been included.

9.7 4.4 Level III Autonomy - Concept Annual Recurring Cost Comparison

Figure 9 7 4-5 presents a comparison of NASA and DoD expenses for a Level III autonomy Space Tug design under the concepts

1) Separate and equal NASA and DoD operation
2A) Single facility, NASA owned, DoD tenant
2B) Single facility, DoD owned, NASA tenant

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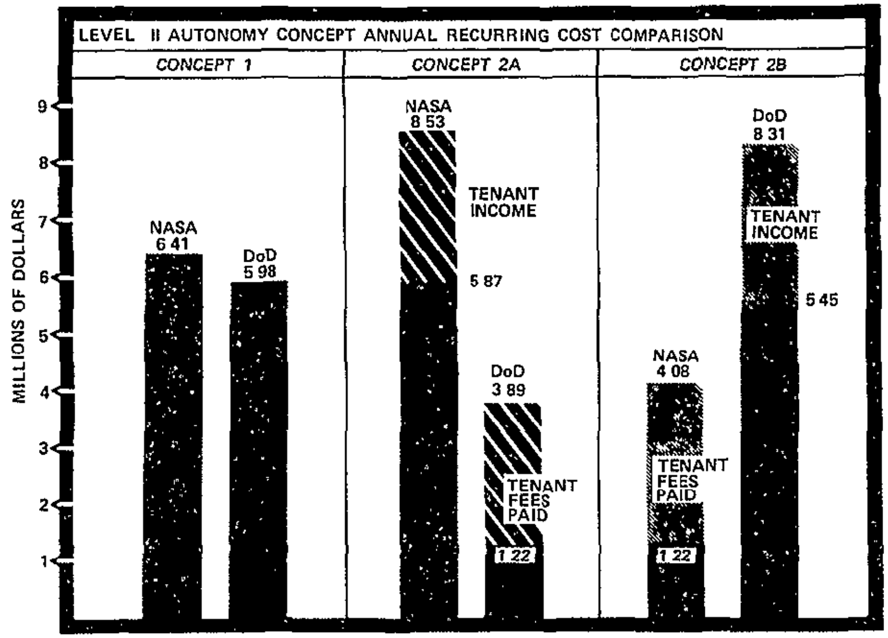


TOTAL ALTERNATIVE RECURRING COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 2A NASA	ALTERNATIVE 2A DOD	ALTERNATIVE 2B NASA	ALTERNATIVE 2B DOD
FACILITY MAINTENANCE	20072	22079	26696	0	0	28101
TOC SOFTWARE MAINTENANCE	1104000	1104000	1391040	0	0	1391040
DATA SYSTEM MAINTENANCE	134458	134458	201687	0	0	201687
SUSTAINING TOC ENGINEERING	2016000	1794240	2913120	0	0	2802240
SUSTAINING TOC FLT CNTL ENGINEERING	1920000	1708800	2774400	0	0	2668800
NETWORK RENTAL	212772	212772	212772	212772	21 772	212772
TUG SOFTWARE MAINTENANCE	1008000	1008000	1008000	1008000	1008000	1008000
TOTALS	6415302	5984349	8527714	1220772	1220772	8312639

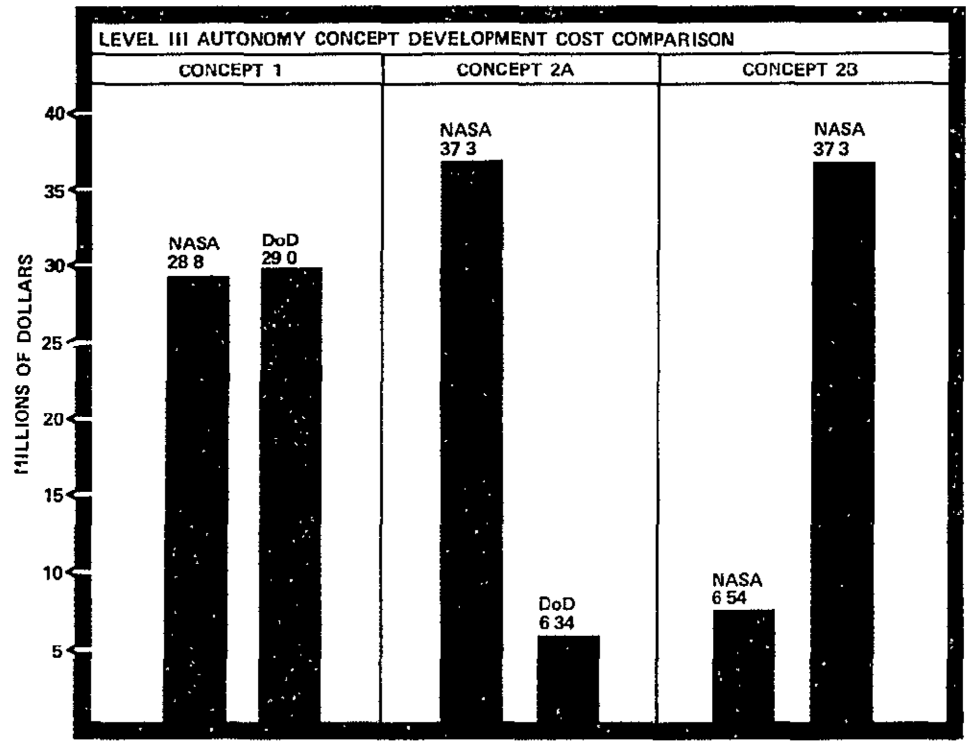
DOD TENANT COSTS ALTERNATIVE 2A

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	6624
TOC SOFTWARE MAINTENANCE	287040
DATA SYSTEM MAINTENANCE	67229
SUSTAINING TOC ENGINEERING	897120
SUSTAINING TOC FLT CNTL ENGINEERING	854400
NETWORK RENTAL	0
TUG SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	15969
DATA SYSTEM	406851
OPERATIONS STAFF EQUIPMENT	123288
TOTAL	2658521

NASA TENANT COSTS ALTERNATIVE 2B

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	6022
TOC SOFTWARE MAINTENANCE	287040
DATA SYSTEM MAINTENANCE	67229
SUSTAINING TOC ENGINEERING	1008000
SUSTAINING TOC FLT CNTL ENGINEERING	960000
NETWORK RENTAL	0
TUG SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	14518
DATA SYSTEM	406851
OPERATIONS STAFF EQUIPMENT	112080
TOTAL	2861739

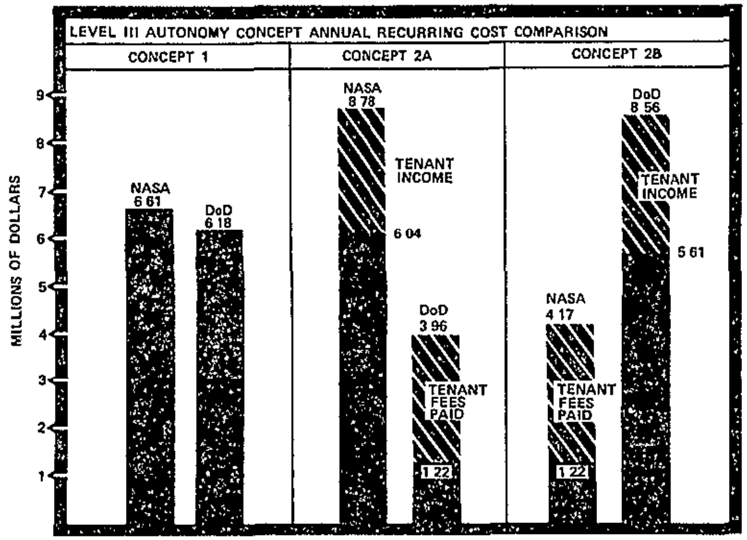
Figure 9 7 4 3 Level II Autonomy Concept Annual Recurring Cost Comparison



TOTAL ALTERNATIVE DEVELOPMENT COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 2A NASA	ALTERNATIVE 2A DOD	ALTERNATIVE 2B NASA	ALTERNATIVE 2B DOD
PHYSICAL PLANT	423620	465892	563414	0	0	563523
TOC SOFTWARE DEVELOPMENT	15559751	15559751	19380783	1578037	1780921	19380783
DATA SYSTEM	7015618	7015618	10523427	0	0	10523427
OPERATIONS STAFF EQUIPMENT	1120800	1232880	2107104	0	0	2129520
TUG SOFTWARE DEVELOPMENT	4757902	4757902	4757902	4757902	4757902	4757902
TOTALS	28877690	29032042	37305630	6335939	6538823	37355155

Figure 9.7.4-4 Level III Autonomy Concept Development Cost Comparison



TOTAL ALTERNATIVE RECURRING COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 2A NASA	ALTERNATIVE 2A DOD	ALTERNATIVE 2B NASA	ALTERNATIVE 2B DOD
FACILITY MAINTENANCE	20072	22079	26696	0	0	28101
TOC SOFTWARE MAINTENANCE	1296000	1296000	1632960	0	0	1632960
DATA SYSTEM MAINTENANCE	136795	136795	208192	0	0	208192
SUSTAINING TOC ENGINEERING	2016000	1794240	2913120	0	0	2802240
SUSTAINING TOC FLT CNTL ENGINEERING	1920000	1708800	2774400	0	0	2668800
NETWORK RENTAL	212772	212772	212772	212772	212772	212772
TUG SOFTWARE MAINTENANCE	1008000	1008000	1008000	1008000	1008000	1008000
TOTALS	6611638	6180686	8776140	1220772	1220772	8561065

NASA TENANT COSTS ALTERNATIVE 2 A

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	6022
TOC SOFTWARE MAINTENANCE	336960
DATA SYSTEM MAINTENANCE	69397
SUSTAINING TOC ENGINEERING	1008000
SUSTAINING TOC FLT CNTL ENGINEERING	960000
NETWORK RENTAL	0
TUG SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	14518
DATA SYSTEM	438476
OPERATIONS STAFF EQUIPMENT	11[illegible]080
TOTAL	2945453

DOD TENANT COSTS ALTERNATIVE 2 A

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	6624
TOC SOFTWARE MAINTENANCE	336960
DATA SYSTEM MAINTENANCE	69397
SUSTAINING TOC ENGINEERING	8971[illegible]0
SUSTAINING TOC FLT CNTL ENGINEERING	854400
NETWORK RENTAL	0
TUG SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	15969
DATA SYSTEM	438476
OPERATIONS STAFF EQUIPMENT	123288
TOTAL	2742235

Figure 9 7 4-5 Level III Autonomy Concept Annual Recurring Cost Comparison

Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and that DoD costs are comparable to NASA costs for similar functions

The shift in costs to increase the host's net outlay in Concepts 2A and 2B does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assts Tenant income and tenant fees paid are indicated

The costs presented update and supercede the figures presented in the Space Tug Baseline Operations Plan (IBM No. 74W-0025) dated November, 1974

9.7.5 Rationale for Selection of Concept 1, Level II

Concept 1 was chosen as most likely to be implemented on the basis that sharing of a real-time operational facility between agencies having dissimilar security requirements would be unworkable over a program of 10 years duration

Level II autonomy was selected because the higher autonomy space vehicle has the potential to reduce ground support below the current calculated minimum A high autonomy Space Tug is technically feasible with no advance in the state-of-the-art

The technique used to establish the above conclusions is an adaptation of the Kepner-Tregoe Decision Analysis methodology to the parameters of the Tug program.

Six objectives were established. An objective, in Kepner-Tregoe context, is a factor or consideration to be optimized Differing implementations, or "Alternatives" have differing impacts upon the objectives. In order to quantify these impacts and place the values of the objectives into perspective, each objective is given a "Rank", which is a numerical weight between 1 and 10 establishing the relative importance of the objective

The impact of each alternative is established by analysis of the alternative and the estimation of the effect on the objective, a number between 0 and 10 In assessing the impact of alternatives, the sense of the assessing is that numerical value increases as "desirability" increases. For example, cost is an objective which is inversely related to desirability. Thus, higher cost results in a lower numerical value

Once the impact of each alternative on each objective is established, a computer program performs the computations required to establish a final relative ranking of the alternatives.

The process is identical for establishing the undesirable attributes of each alternative. The final results are obtained by weighting the finishing order of desirable and undesirable alternatives and selecting the best composite alternative.

Three experienced mission operations engineers were given the task of establishing the impact of the Space Tug alternatives on a fixed set of objectives and adverse consequences. Figure 9.7.5-1 illustrates the Kepner-Tregoe input sheet.

INPUT DATA SHEET		LEVEL II CONCEPTS			LEVEL III CONCEPTS		
OBJECTIVE	RANK	1	2A	2B	1	2A	2B
		CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
COST	10						
SUCCESS	9						
OPERABILITY	8						
MOD ABILITY	5						
ACCESS	5						
ADVERSE CONSEQUENCES							
PRE–EMPTION	10						
HUMAN ERROR	9						
CHANGE CONTROL	6						
MOTIVATION	5						

- INPUT DATA FROM 3 EXPERIENCED ENGINEERS
- WEIGHTED (+5 TO –5) INDIVIDUAL SELECTIONS
- NUMERICAL SUM OF FACTORS/CONCEPT
- SELECTED "BEST SCORE" CANDIDATE

Figure 9 7 5-1 Space Tug Concept Trade

Table 9 7 5-1 (a) presents the summary results of the three inputs after computation and rank-ordering. The first column of Table 9.7 5-1 (a) is the weighting factor for rank-order This is used to further drive apart the finishing position of each alternative. Table 9 7 5-1 (b) is the final weighting matrix. The weighting factor of Table 9 7 5-1 (a) is multiplied by the number of times the alternative appears in the row relative to the weighting factor Thus, since alternative 1 appears four times in the row having a weighting factor of 5, it is given a score of 20 in column one of Table 9.7 5-1 (b) When that operation is completed, the columns are summed to give the final selection

The Space Tug alternative scoring highest was Level II autonomy - Concept 1, with Level III/Concept 1 and Level II/Concept 2B ranked second and third, respectively This leads to the conclusion that, based upon the objectives and adverse factors analyzed, Level II autonomy - Concept 1 implementation is the best selection for Space Tug

Table 9.7 5-1. Kepner-Tregoe Results

WEIGHT VALUES	(a) MAN-A A	MAN-A O	MAN-B A	MAN-B O	MAN-C A	MAN-C O	(b) CASE NUMBERS 1	2	3	4	5	6
5	1	3	1	1	1	3	20	0	10	0	0	0
3	4	6	4	4	4	1	3	0	0	12	0	3
1	3	1	2	3	2	4	1	2	2	1	0	0
-1	2	4	5	6	3	6	0	-1	-1	-1	-1	-2
-3	6	2	3	5	5	2	0	-6	-3	0	-6	-3
-5	5	5	6	2	6	5	0	-5	0	0	-15	-10
			CASE NUMBERS				24	-10	8	12	-22	-12

CASES IN ORDER OF FINAL SCORE

1 = LEVEL II/CONCEPT 1 (24)
2 = LEVEL III/CONCEPT 1 (12)
3 = LEVEL II/CONCEPT 2B (8)

IUS/SPACE TUG OPERATIONS TRANSITION 10

This section develops the rationale for and presents the recommended mode of transitioning from IUS operations to Space Tug operations. The IUS operations concept is summarized in terms of the developmental work breakdown structure (XXX-WBS) and compared to the equivalent Space Tug work breakdown structure (320-WBS). This comparison categorizes the WBS elements onto four groups

- Common to XXX-WBS and 320-WBS
- Unique to XXX-WBS
- Unique to 320-WBS
- Modifiable from XXX-WBS to 320-WBS

After the groups are identified, the XXX-WBS and 320-WBS are combined into a master IUS/Tug mission operations development plan. This integrated plan is supported by a composite work breakdown structure, program plan bar-chart, a manpower estimate covering the first five years, and a PERT chart of the composite activities.

10 1 DEFINITION OF FLIGHT CONTROL OPERATIONAL ELEMENTS

This section summarizes the operational support elements (XXX-WBS) developed for the Expendable Interim Upper Stage in Volume II of this report, and the Space Tug Operational Elements (320-WBS) developed in this volume.

10 1 1 IUS Work Breakdown Structure

Table 10 1 1-1 presents the IUS work breakdown structure The "XXX" desinnates a three digit program identifier which NASA will supply when the IUS achieves full program status

Portions of the IUS WBS dictionary have been extracted from Volume II and are presented in Table 10.1.1-2 The complete WBS heirarchy is not shown, since comparisons with the similar elements of the Space Tug WBS must be made at the lowest level of detail, i e , where a "product" is developed.

Table 10 1 1-1. IUS WBS Identification Number Sequence

IDENTIFICATION NUMBER	ELEMENT	LEVEL
XXX	IUS PROJECT	3
XXX-01	Project Management	4
XXX-01-01	Cost/Performance Management	5
XXX-01-01-01	Cost Control System	5
XXX-01-01-02	Schedule Control System	6
XXX-01-02	Project Direction	5
XXX-01-02-01	Development Management	6
XXX-01-02-01-01	Contract Software Development	7
XXX-01-02-01-02	Plan Facility Utilization	7
XXX-01-02-01-03	Computer Utilization Plan	7
XXX-01-02-01-04	Maintenance Schedule	7
XXX-01-02-01-05	Hire Control and Support Staff	7
XXX-01-02-01-06	Obtain IUS System Characteristics	7
XXX-01-02-01-07	Prepare IUS Interagency Documents	7
XXX-01-02-01-08	IUS Interagency Coordination	7
XXX-01-02-02	Quality Management	6
XXX-01-02-03	Logistics Management	6
XXX-01-02-04	Engineering Administration	6
XXX-01-03	Information Management	6
XXX-02	Systems Engineering	4
XXX-02-01	IUS Systems Engineering	5
XXX-02-01-01	Master Launch Schedule Analysis	6
XXX-02-01-02	IUS Mission Characterization	6
XXX-02-01-03	Determine IUS Failure Modes	6
XXX-02-02	Shuttle Interface	5
XXX-02-03	Payload Interface	5
XXX-02-04	Sustaining Engineering	5
XXX-02-04-01	Flight Control Engineering	6
XXX-02-04-01-01	Mission Phase Manning Requirements	7
XXX-02-04-01-02	IUS Console Position Guidelines	7
XXX-02-04-01-03	Define IUS Operator Certification/Criteria	7
XXX-02-04-01-04	Validation Test Requirements-Fundamental IUS Ground Programs	7
XXX-02-04-01-05	IUS Ground Validation Test Requirements	7
XXX-02-04-02	Flight Support Engineering	6
XXX-02-04-02-01	Select Operational Data System	7
XXX-02-04-03	Mission Engineering	6
XXX-02-04-03-01	IUS Mission Planning and Optimization	7
XXX-02-04-03-02	IUS Abort Planning	7
XXX-02-04-05	Mission Evaluation Engineering	6
XXX-02-04-05-01	IUS Post Mission Reports	7
XXX-03	IUS Vehicle Main Stage	4
XXX-05	Logistics	4
XXX-05-01	Transportation and Handling	5
XXX-05-02	Training	5

Table 10.1.1-1. IUS WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
XXX-05-02-01	Simulators and Equipment	6
XXX-05-02-02	Ground Crew Training	6
XXX-05-02-03	Flight Operations Crew Training	6
XXX-05-02-03-01	IUS Training Requirement/Criteria/Simsked	7
XXX-05-02-03-02	Develop IUS Training Material	7
XXX-05-02-03-03	Design IUS Mission Simulation	7
XXX-05-02-03-04	IUS Classroom Training	7
XXX-05-02-03-05	IUS Mission Simulation Training	7
XXX-06	Facilities	4
XXX-06-01	Manufacturing	5
XXX-06-02	Test	5
XXX-06-03	Maintenance and Refurbishment	5
XXX-06-04	ETR Launch	5
XXX-06-05	WTR Launch	5
XXX-06-06	Flight Operations Facility	5
XXX-06-06-01	Size Facility/Design Physical Plant	6
XXX-06-06-02	Construct Physical Plant	6
XXX-07	Ground Support Equipment (GSE)	4
XXX-07-01	Manufacturing and Test GSE	5
XXX-07-02	Eastern Test Range GSE	5
XXX-07-03	Western Test Range GSE	5
XXX-07-04	Flight Operations GSE	5
XXX-07-04-01	Install Operational Data System	6
XXX-07-04-02	Install Operational Consoles/Hardware	6
XXX-08	Vehicle Test	4
XXX-09	Launch Operations	4
XXX-10	Flight Operations	4
XXX-10-01	Mission Planning and Documentation	5
XXX-10-01-01	Develop IUS Procedures and Rules	6
XXX-10-01-02	IUS Mission Failure Effects	6
XXX-10-01-03	Analyze IUS Component Characteristics	6
XXX-10-01-04	Flight Control Systems Handbook	6
XXX-10-01-04-01	Prepare IUS Systems Handbook	7
XXX-10-01-04-02	Publish/Update IUS Systems Handbook	7
XXX-10-01-05	IUS Network Interface Documentation	6
XXX-10-01-05-01	Define Network Tracking Requirements	7
XXX-10-01-05-02	Network Tracking Validation Procedures	7
XXX-10-01-05-03	IUS Network Data Handling Pequirements	7
XXX-10-01-05-04	IUS Network Data Validation Procedures	7
XXX-10-02	Operational Preparations	5
XXX-10-02-01	Design Network Interface System	6
XXX-10-02-02	Console Organization	6
XXX-10-02-03	IUS Display Format Design	6
XXX-10-03	Mission Readiness Testing	5
XXX-10-03-01	Network Tracking Validation Tests	6
XXX-10-03-02	IUS Network Validation Tests	6
XXX-10-04	Conduct IUS Mission Operations	5
XXX-11	Refurbishment and Integration	4

Table 10.1 1-1 IUS WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
XXX-15	Software	4
XXX-15-01	Flight Software	5
XXX-15-01-01	Plan Flight Software Development	6
XXX-15-01-02	Baseline Flight Program Development	6
XXX-15-01-02-01	EDD - IUS Flight Program	7
XXX-15-01-02-02	Program IUS Flight Software	7
XXX-15-01-02-03	IUS Flight Program Verification	7
XXX-15-01-03	Mission Specific Program Modification	6
XXX-15-01-03-01	IUS Mission Specific EDD	7
XXX-15-01-03-02	IUS Mission Specific Program	7
XXX-15-01-03-03	IUS Mission Program Verification	7
XXX-15-02	Ground Software	5
XXX-15-02-01	Plan Ground Software Development	6
XXX-15-02-02	Equation Definition	6
XXX-15-02-02-01	EDD - Executive/Tracking/Planning	7
XXX-15-02-02-02	EDD - IUS Dndata/Updata/Sim	7
XXX-15-02-03	Programming	6
XXX-15-02-03-01	Program Ground EX/TK/Planning SW	7
XXX-15-02-03-02	Program IUS Dndata/Updata/Sim	7
XXX-15-02-04	Program Verification	6
XXX-15-02-04-01	Verify Executive/TK/Planning SW	7
XXX-15-02-04-02	Verify IUS Dndata/Updata/Sim	7
XXX-15-02-05	Mission Specific Simulation	6
XXX-15-02-05-01	Program IUS Mission Simulation	7
XXX-15-03	Computer Selection Support	5
XXX-15-03-01	Estimate Ground Software Size	6
XXX-16	Orbiter Interface	4

Table 10 1 1-2 IUS Operational Element Dictionary

XXX-02-01-01 MASTER LAUNCH SCHEDULE ANALYSIS

The master Launch Schedule will be analyzed to determine the type, spacing, and frequency of IUS flights. This task will establish the range of mission types, trajectories, payload accommodations and control facility utilization requirements across the IUS operational period. This task is a predecessor to the establishment of IUS mission characteristics and control facility utilization planning.

XXX-01-02-01-01 CONTRACT SOFTWARE DEVELOPMENT

This task includes all effort necessary to prepare a Statement of Work, evaluate proposals and provide financial, contracting and procurement support in order to place an outside contractor under contract for development of ground and flight software.

XXX-01-02-01-02 PLAN FACILITY UTILIZATION

This task includes all efforts involved in establishing a coherent plan for the utilization of a Mission Control facility This will include such things as scheduling of activities, program sharing, office, canteen, technical support area and other generic requirements which impact facility design.

XXX-15-01-01 PLAN FLIGHT SOFTWARE DEVELOPMENT

This task includes all efforts required to establish a schedule for development of the flight software, establish design concept validation procedures, establish the necessity for, and required characteristics of, hybrid and interpretive simulators, and establishing controls and feedback to insure customer requirements on the IUS flight software are fulfilled

XXX-15-02-01 PLAN GROUND SOFTWARE DEVELOPMENT

This task includes all efforts necessary to establish a plan for the development of IUS ground support software. Included will be the advisability of transforming software modules from existing ground control systems, establishment of the basic data processing techniques, planning the use of existing ground system simulators, and establishing ground program organization and source strings.

XXX-02-04-01-01 MISSION PHASE MANNING REQUIREMENTS

This task includes all efforts required to establish the types and quantity of personnel required to support IUS flight control and flight support activities. It will include an analysis of the mission density, the overlap between adjacent modules in the mission structure and will establish the control and support personnel necessary to accomplish the IUS missions with a minimum loss of productive man hours.

XXX-01-02-01-03 COMPUTER UTILIZATION PLAN

This task includes all efforts required to develop and enforce a plan to maximize the utilization of the computational facility incorporated in the IUS ground control complex. This will include a pre-emption hierarchy, mission planning schedule, mission operation schedule, batch processing schedule, etc

XXX-01-02-01-04 MAINTENANCE SCHEDULE

This task establishes the housekeeping and periodic maintenance requirements of the control center and associated equipments This task includes the contracting for, and administration of, specific external maintenance of the data system, plant environmental control mechanisms, and janitorial services. Periodic and specific maintenance of the flight control and flight support console items will be conducted by the permanent party flight support staff.

XXX-01-02-01-05 HIRE CONTROL AND SUPPORT STAFF

This task includes all efforts required to procure competent personnel to perform flight control tasks in the technical disciplines of propulsion, avionics, networks, communication, guidance, dynamics and data selection It also includes the efforts required to hire flight support personnel in the technical disciplines of facility supervisor, data systems, maintenace operations and software support.

XXX-10-02-02 CONSOLE ORGANIZATION

This task includes all efforts necessary to establish the requirements for location of console display and control devices to the satisfaction of the console operating personnel.

XXX-10-02-01 DESIGN NETWORK INTERFACE

This task includes the engineering effort necessary to establish the interface with the data acquisition network. It specifically includes telemetry decommutation and special processing, command processing and tracking format and processing requirements The output of this task will be the operational requirements for a network interface systems design which will include suggested hardware items.

XXX-15-03-01 ESTIMATE GROUND SOFTWARE SIZE

This task analyzes the equation defining document for ground software and establishes a lower boundary upon the data system memory size and central processor unit speed requirements. For maximum cost-effectiveness this task must be completed prior to the selection of an operational data system.

XXX-02-04-02-01 <u>SELECT OPERATIONAL DATA SYSTEM</u>

This task includes all efforts required to establish the integrated requirements of an operational data system and takes into account the ground software size estimate, the computer utilization plan, and growth factors. This task also includes all procurement and purchase operations necessary in the buy of an operational data system, and the engineering of the data system configuration.

XXX-07-04-01 <u>INSTALL OPERATIONAL DATA SYSTEM</u>

This task includes all efforts by the data system contractor to install, diagnose and checkout the completed system installation. At the end of this task, the data processing system will be on-line and operational ready to support future data processing activities.

XXX-06-06-01 <u>SIZE FACILITY/DESIGN PHYSICAL PLANT</u>

Prior to beginning this task, the operational data system will have been selected, the network interface design will have been completed and equipment selected, and the console equipment designed and ordered. This task includes the architectural design of the facility.

XXX-06-06-02 <u>CONSTRUCT PHYSICAL PLANT</u>

This task includes the efforts involved by a building contractor to perform site preparation, construction of a physical plant, environmental control and electrical installations on the structure.

XXX-07-04-02 <u>INSTALL OPERATIONAL CONSOLES</u>

This task includes the installation of the console hardware and associated interface equipments. This task presumes that the consoles will be delivered to the finished physical plant by a vendor and then will be installed by flight support technicians.

XXX-15-02-02-01 <u>EQUATION DEFINING DOCUMENT - EXECUTIVE/TRACKING/PLANNING SOFTWARE</u>

This task includes those efforts in the definition and analysis leading to the development of the equations and algorithms to be utilized in the fundamental IUS ground programs.

XXX-02-04-01-04 <u>VALIDATION TEST REQUIREMENTS - FUNDAMENTAL IUS GROUND PROGRAMS</u>

This task includes the establishment of proof-of-performance parameters for the software which is fundamental to the IUS ground operations. This task establishes the vital criteria against which the program performance is to be evaluated, and should be conducted independently of the Equation Definition generation.

XXX-10-01-05-01 DEFINE GROUND NETWORK TRACKING REQUIREMENTS

This task includes all efforts necessary to determine the required accuracy of the tracking network The output of this task will be utilized to establish performance requirements on the network, which will be administered by an agency other than the Mission Control NASA Center

XXX-10-01-05-02 NETWORK TRACKING VALIDATION PROCEDURES

This task includes those systems analyses, mission engineering, flight control and flight support efforts required to develop a checkout procedure which will exercise the tracking capabilities of the support network from the flight control and flight support consoles in the Mission Control Center The output of this task will be a procedural checklist which will be followed in the actual testing of the network proof-of-performance

XXX-10-03-01 NETWORK TRACKING VALIDATION TESTS

This task includes all efforts required to set up and conduct specific premission tests of the tracking capabilities and tracking accuracies of the support network This will involve the generation of tapes to simulate IUS vehicles and ground receiving tracking stations, the distribution and execution of procedures previously prepared and the evaluation of test results.

XXX-15-02-03-01 PROGRAM GROUND TRACKING, PLANNING AND EXECUTIVE ROUTINES

This task depends on the generation of an adequate Equation Defining Document at a prior time, and includes the programming of all fundamental routines

XXX-15-02-04-01 VERIFY EXECUTIVE TRACKING AND PLANNING SOFTWARE

This task verifies that the intent of the Equation Defining Document has been implemented in the developed programs by testing the coded program under critical operational situations and includes the development of any special tools or simulators necessary in the accomplishment of this task

XXX-01-02-01-06 OBTAIN IUS SYSTEM CHARACTERISTICS

This task includes all efforts necessary to acquire, catalog, define and analyze the operational characteristics of the IUS system The output of this task is utilized in the development of flight controller display designs, network telemetry and update interface system design and as primary input into the determination of operational failure modes

XXX-02-01-02 IUS MISSION CHARACTERIZATION

This task accepts the output of the master launch schedule analysis task and operates on that output to determine the specific characteristics of all defined IUS missions. The output of this task is utilized in the determination of mission phase manning requirements, definition of IUS operator certification (and criteria for certification), a computer

utilization plan for the IUS portion of the Shuttle era and the associated maintenance schedule

XXX-15-01-02-01 EQUATION DEFINING DOCUMENT - IUS FLIGHT PROGRAM

This task includes basic conceptual work on the requirements for flight software, customer support and flight software definition, definitions of equations pertaining to vehicle dynamics, a design of algorithm techniques and the associated simulation equipments, the generation of a program requirements document known as the Equation Defining Document (EDD), control of requirements, performance of software implementation studies, analysis of sample calculations, definition of flight control functional interfaces, definition of hardware interfaces, and miscellaneous preliminary analysis.

XXX-15-02-02-02 IUS DOWN DATA, UP DATA AND SIMULATION GROUND SOFTWARE

This task includes all efforts required to create an Equation Defining Document (EDD) for those ground software modules which are specifically oriented to the IUS. The output of this task is an Equation Defining Document against which the ground IUS-peculiar software will be programmed.

XXX-02-04-01-05 IUS GROUND VALIDATION TEST REQUIREMENTS

This task includes all efforts required to establish the criteria for acceptance or rejection of IUS-peculiar ground software. This task is performed independently of the programming effort and is specifically to establish proof-of-performance standards against which the program will be judged.

XXX-02-01-03 DETERMINE IUS FAILURE MODES

After the IUS system characteristics have been obtained, categorized and defined, the systems will be analyzed for high-probability failure modes. The output of this task will be a list of potential failures which can impact the operational performance of the vehicle. Failures of a cosmetic nature will not be considered. The output of this task is a list of high probability failure modes which will then be analyzed for the overall mission effect of that failure.

XXX-10-02-03 IUS DISPLAY FORMAT DESIGN

This task includes all efforts required to establish the organization, display format and engineering units for flight control and flight support personnel digital TV presentation. This task also includes all efforts directed toward the definition of the special processing requirements, remote site and control center logical operations, limit sensing, event light triggering, etc.

XXX-10-01-02 IUS MISSION FAILURE EFFECTS ANALYSIS

Once the IUS failure modes have been identified and categorized, the occurance of these failures at various points in the flight must be evaluated for overall mission effect. The output of this task will be a series of scenarios against which pre-thought decisions may be constructed

XXX-05-02-03-03 DESIGN IUS MISSION SIMULATION

This task includes all efforts required to integrate the results of the IUS procedures and rules, the optimum and abort mission timelines, and operator training criteria into an IUS mission specific simulation design This task will be accomplished both in the DDT&E phase and in the recurring phase of the IUS program A specific simulation design will be formulated for each mission The flight controller and flight support personnel will be trained against the mission specific simulation in preparation for their operational roles. The output of this task is a set of malfunctions, predicted responses and operator performance evaluation criteria.

XXX-10-01-03 ANALYZE IUS COMPONENT CHARACTERISTICS

This task includes all efforts required to assemble basic operational information describing the characteristics of the operationally significant components of the IUS vehicle The output of this task is a compendium of nominal operational performance, characteristic performance curves, expectations of behavior, etc. This output will be utilized in the preparation of training material and reference handbook

XXX-05-02-03-01 IUS TRAINING REQUIREMENTS, EVALUATION CRITERIA AND SIMULATION SCHEDULE

This task accepts as inputs the IUS console position guidelines, operator certification criteria, procedures and mission rules and from that information creates a requirement of training criteria against which successful training is judged, a definition of kind and content of simulations and a schedule for classroom and simulation training for a particular mission This task is a recurring task.

XXX-10-01-04-01 PREPARE IUS SYSTEM HANDBOOK

This task includes all efforts required to generate simplified schematic diagrams, simplified interface connections, a summary of component characteristics, prediction of mission events and performance curves, and inherent IUS constraints and limitations

XXX-10-01-04-02 PUBLISH AND UPDATE IUS SYSTEM HANDBOOK

The basic publication of an IUS system handbook will incorporate the information prepared for that purpose under one cover. The updating of a system handbook will be on a by-mission, and as required, basis, and thus is an iterative task. Major updates and changes to the IUS baseline design must be incorporated into the systems handbook prior to the utilization of that vehicle for a mission.

XXX-05-02-03-02 DEVELOP IUS TRAINING MATERIAL

This task includes the development and preparation of all materials required for classroom training of flight controllers and flight support personnel This includes text books, handouts, view graphs, reference material, etc.

XXX-05-02-03-04 CLASSROOM TRAINING

This task includes the instructor's time, student's time, and the facilities required for conducting classroom training in the characteristics of an IUS vehicle, the mission, and support networks. Training will be conducted by flight control and flight support personnel in addition to their normal operational tasks.

XXX-10-01-05-03 IUS NETWORK DATA HANDLING REQUIREMENTS

This task includes all efforts required to produce a document levying specific data handling, processing, and special processing requirements on the supporting network. This includes both updata and downdata processing.

XXX-10-01-05-05 IUS NETWORK DATA VALIDATION PROCEDURES

This task includes all efforts required to establish proof-of-performance criteria for the acceptance test of IUS peculiar ground software.

XXX-10-03-02 IUS NETWORK VALIDATION TESTS

This task includes all efforts required to conduct tests of the network handling of IUS-peculiar software, including the providing of vehicle simulation tapes to remote sites of the ground data acquisition network, providing the procedures to remote operators, and providing personnel to conduct these tests.

XXX-15-02-03-02 PROGRAM IUS DOWN DATA, UP DATA AND SIMULATION SYSTEM

This task includes all efforts required to design an overall software system based on execution rates, input/output requirements, and response restrictions, design and develop IUS specific program modules, generating a detailed software design document; participation in design reviews, perform software integration testing, participate in change reviews and update software, provide configuration control and perform program generation, delivery and validation.

XXX-15-01-02-02 PROGRAM IUS FLIGHT SOFTWARE

This task includes all efforts required to develop pre-flight and flight software to satisfy baseline requirements. Included are performance of overall software system design based on execution rates, input/output requirements, and response time restrictions; design and develop executive and application program modules; generate detailed software design documentaton, participate in design reviews; perform systematic integration

testing of software, update software as a result of change activity, participate in configuration control, perform program delivery generation and validation, and provide customer support as required

XXX-15-02-04-02 <u>VERIFY IUS DOWN DATA, UP DATA SIMULATION PROGRAMMING</u>

This task includes all activities involved to insure, through systematic testing by a independent functional area, that the IUS-peculiar ground software satisfies all requirements levied upon it by the Equation Definition Document. This includes analysis of software requirements to insure accuracy, adequacy, and completeness, generation of a detailed testing plan, performance of systematic tests utilizing interpretive simulators, analysis of software listings, analysis of hardware/software compatibility and validation of all changes made to the basic software package

XXX-02-04-01-02 <u>IUS CONSOLE POSITION GUIDELINES</u>

This task includes all activities required to establish generic position responsibilities as a function of console and technical discipline This activity is based upon the mission phase manning requirements and the output is utilized as one input to the mission simulation design and to the IUS requirements criteria, simulation and schedule tasks. The output of this task establishes the organizational reporting tree authority invested in the greatest positions and both technical and hierarchial relationships

XXX-02-04-03-01 <u>IUS MISSION PLANNING AND OPTIMIZATION</u>

This task includes the basic design of trajectory, timing of burns, and error propagation analysis leading to the design of the mission flight plan. This task will be performed on the operational computer utilizing software specially developed for the purpose The output of this task, and the output from the associated IUS abort planning task are utilized to establish the mission specific deviations from the IUS flight program baseline, and to provide an input to the mission specific simulation development

XXX-10-01-01 <u>DEVELOP IUS PROCEDURES AND RULES</u>

The specific rules and procedures utilized during the mission will consist of a fundamental set of procedures and rules which are applicable across all IUS missions, and a mission specific set of rules and procedures. The output of this task is a document containing all predefined mission decisions, a document containing basis step-by-step implementation procedures, a set of predefined contingency procedures and a vehicle command listing.

XXX-02-04-03-02 <u>IUS ABORT PLANNING</u>

After the basic mission planning and optimization has been completed, certain off-nominal malfunction, abort and contingency conditions must be investigated and contingency operational procedures developed to handle those situations. This task utilizes special software programmed into the operational computer

system and is iterated for each mission. The output of this task includes alternative mission definitions, abort profiles, and degraded mission plans This task is conducted roughly in parallel with the development of IUS procedures and mission rules in order that cross-feed between the abort planning and contingency operational planning may take place.

XXX-01-02-01-08 IUS INTERAGENCY COORDINATION

This task includes all efforts required to establish mutual agreements with DoD and NASA centers supporting IUS mission operations. This includes the coordination of program support requirement and ground support planning

XXX-15-01-02-03 IUS FLIGHT PROGRAM VERIFICATION

The objective of program verification is to insure, thru systematic testing by a independent functional area, that the flight software satisfies all requirements levied on it by the equation defining document. To accomplish this objective, the following activities are performed analysis of software requirements, generation of a detailed testing plan, performance of systematic tests, analysis of software listings, comparison of flight software derived results with independently generated results, analysis of hardware/software compability, reverification of all changes made to the software and generation of documented test results.

XXX-01-02-01-07 PREPARE IUS INTERAGENCY DOCUMENTATION

This task includes all efforts required to prepare interagency and inter-center coordination documents. A ground support plan and documents which levy requirements on other government agencies or other NASA centers. The output of this task is required for the interagency coordination task.

XXX-15-02-05-01 PROGRAM IUS MISSION SIMULATION

This task includes all efforts required to modify the baseline IUS simulator to incorporate mission specific profiles and contingency cases. This task accepts as inputs the output from the IUS mission planning and optimization task, and the IUS abort planning task, as well as outputs from IUS basic simulation design. This task is iterative and must be repeated for each flight. This task is in a sense a mission specific simulation application module.

XXX-15-01-03-01 IUS MISSION SPECIFIC EQUATION DEFINING DOCUMENT (EDD)

This task includes all efforts required to modify the definition of the baseline IUS flight program to incorporate mission specific peculiarities. This task is iterative and must be repeated prior to each flight.

XXX-15-01-03-02 IUS MISSION SPECIFIC PROGRAMMING

This task develops the "application module" which incorporates the specific deviations from the baseline program required by the following IUS mission This task is iterative and must be repeated prior to each flight

XXX-15-01-03-03 IUS MISSION PROGRAM VERIFICATION

This task includes efforts necessary to analyze flight program implementation of the equation defining document for this "application module " The task includes generation of a detailed testing plan to insure that all requirements are satisfied, the performance of systematic tests, and generation of a test results document

XXX-05-02-03-05 IUS MISSION SIMULATION TRAINING

This task includes the simulation of the specific IUS mission for nominal and contingency performance cases wherein the flight support personnel conduct the simulation and the flight control personnel are judged on their ability to respond to contingency situations and to recognize nominal vehicle performance This task is iterative and must be repeated prior to each flight.

XXX-10-04 CONDUCT IUS MISSION OPERATIONS

This task includes all efforts necessary to provide control and support to the IUS vehicle in prelaunch, orbital operations and placement mission phases This task requires the total attention of the flight control team, the flight support team, and other personnel. This task is the culmination of all prior efforts

XXX-02-04-05-01 IUS POST MISSION REPORTS

This task includes all efforts required to generate two post mission reports. An evaluation and critique report is prepared by the flight controllers which define the performance of the vehicle as viewed from the position of a real time console operator. The third report is the maintenance and operations interface report which evaluates the performance of the data gathering and tracking network during the mission.

XXX-02-04-01-03 DEFINE IUS OPERATOR CERTIFICATION CRITERIA

This task includes all efforts required to analyze the functions of the consoles and to establish appraisal criteria by which the operator's performance may be evaluated. As with all real time operations, console operators must demonstrate the ability to perform well under stress. This task analyses the stress situations which the operator will face and establishes the criteria by which the operator's performance and technical adequacy are to be judged

10 1 2 Space Tug Work Breakdown Structure

Table 10 1 2-1 presents the Space Tug work breakdown structure The "320" designation is the index for the Space Tug program

Portions of the Space Tug WBS dictionary are presented in Table 10 1 2-2 The complete WBS hierarchy is not shown, since comparisons with the similar elements of the IUS WBS must be made at the lowest level of detail, i e , where a "product" is developed

Table 10.1 2-1 Space Tug WBS Identification Number Sequence

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320-01	Project Management	4
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320-01-02-01-07	Prepare Tug Interagency Documents	7
320-01-02-01-08	Tug Interagency Coordination	7
320-01-02-02	Quality Management	6
320-01-02-03	Logistics Management	6
320-01-02-04	Engineering Administration	6
320-01-03	Information Management	6
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320-02-01	Tug Systems Engineering	5
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320-02-01-02	Tug Mission Characterization	6
320-02-01-03	Determine Tug Failure Modes	6
320-02-02	Shuttle Interface	5
320-02-03	Payload Interface	5
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320-02-04-05	Mission Evaluation Engineering	6
320-02-04-05-01	Tug Post Mission Reports	7
320-03	Tug Vehicle Main Stage	4
320-05	Logistics	4
320-05-01	Transportation and Handling	5
320-05-02	Training	5

Table 10 1 2-1. Space Tug WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-05-02-01	Simulators and Equipment	6
320-05-02-02	Ground Crew Training	6
320-05-02-03	Flight Operations Crew Training	6
320-05-02-03-01	Tug Training Requirement/Criteria/Simsked	7
320-05-02-03-02	Develop Tug Training Material	7
320-05-02-03-03	Design Tug Mission Simulation	7
320-05-02-03-04	Tug Classroom Training	7
320-05-02-03-05	Tug Mission Simulation Training	7
320-06	Facilities	4
320-06-01	Manufacturing	5
320-06-02	Test	5
320-06-03	Maintenance and Refurbishment	5
320-06-04	ETR Launch	5
320-06-05	WTR Launch	5
320-06-06	Flight Operations Facility	5
320-06-06-01	Size Facility/Design Physical Plant	6
320-06-06-02	Construct Physical Plant	6
320-07	Ground Support Equipment (GSE)	4
320-07-01	Manufacturing and Test GSE	5
320-07-02	Eastern Test Range GSE	5
320-07-03	Western Test Range GSE	5
320-07-04	Flight Operations GSE	5
320-07-04-01	Install Operational Data System	6
320-07-04-02	Install Operational Consoles/Hardware	6
320-08	Vehicle Test	4
320-09	Launch Operations	4
320-10	Flight Operations	4
320-10-01	Mission Planning and Documentation	5
320-10-01-01	Develop Tug Procedures and Rules	6
320-10-01-02	Tug Mission Failure Effects	6
320-10-01-03	Analyze Tug Component Characteristics	6
320-10-01-04	Flight Control Systems Handbook	6
320-10-01-04-01	Prepare Tug Systems Handbook	7
320-10-01-04-02	Publish/Update Tug Systems Handbook	7
320-10-01-05	Tug Network Interface Documentation	6
320-10-01-05-03	Tug Network Data Handling Requirements	7
320-10-01-05-04	Tug Network Data Validation Procedures	7
320-10-02	Operational Preparations	5
320-10-02-01	Design Network Interface System	6
320-10-02-02	Console Organization	6
320-10-02-03	Tug Display Format Design	6
320-10-03	Mission Readiness Testing	5
320-10-03-02	Tug Network Validation Tests	6
320-10-04	Conduct Tug Mission Operations	5
320-11	Refurbishment and Integration	4

Table 10 1.2-1. Space Tug WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-15	Software	4
320-15-01	Flight Software	5
320-15-01-01	Plan Flight Software Development	6
320-15-01-02	Baseline Flight Program Development	6
320-15-01-02-01	EDD - Tug Flight Program	7
320-15-01-02-02	Program Tug Flight Software	7
320-15-01-02-03	Tug Flight Program Verification	7
320-15-01-03	Mission Specific Program Modification	6
320-15-01-03-01	Tug Mission Specific EDD	7
320-15-01-03-02	Tug Mission Specific Program	7
320-15-01-03-03	Tug Mission Program Verification	7
320-15-02	Ground Software	5
320-15-02-01	Plan Ground Software Development	6
320-15-02-02	Equation Definition	6
320-15-02-02-01	EDD - Executive/Planning	7
320-15-02-02-02	EDD - Tug Dndata/Updata/Docking/Sim	7
320-15-02-03	Programming	6
320-15-02-03-01	Program Ground EX/Planning SW	7
320-15-02-03-02	Program Tug Dndata/Updata/Docking/Sim	7
320-15-02-04	Program Verification	6
320-15-02-04-01	Verify Executive/Planning SW	7
320-15-02-04-02	Verify Tug Dndata/Updata/Docking/Sim	7
320-15-02-05	Mission Specific Simulation	6
320-15-02-05-01	Program Tug Mission Simulation	7
320-15-03	Computer Selection Support	5
320-15-03-01	Estimate Ground Software Size	6
320-16	Orbiter Interface	4

320-02-01-01 MASTER LAUNCH SCHEDULE ANALYSIS

The master Launch Schedule will be analyzed to determine the type, spacing, and frequency of Space Tug flights. This task will establish the range of mission types, trajectories, payload accommodations and control facility utilization requirements across the Space Tug operational period. This task is a predecessor to the establishment of Tug mission characteristics and control facility utilization planning.

320-01-02-01-01 CONTRACT SOFTWARE DEVELOPMENT

This task includes all effort necessary to prepare a Statement of Work, evaluate proposals and provide financial contracting and procurement support in order to place an outside contractor under contract for development of ground and flight software.

320-01-02-01-02 PLAN FACILITY UTILIZATION

This task includes all efforts involved in establishing a coherent plan for the utilization of a Mission Control facility. This will include such things as scheduling of activities, program sharing, office, canteen, technical support area and other generic requirements which impact facility design.

320-15-01-01 PLAN FLIGHT SOFTWARE DEVELOPMENT

This task includes all efforts required to establish a schedule for development of the flight software, establish design concept validation procedures, establish the necessity for, and required characteristics of, hybrid and interpretive simulators, and establishing controls and feedback to insure customer requirements on the Space Tug flight software are fulfilled.

320-15-02-01 PLAN GROUND SOFTWARE DEVELOPMENT

This task includes all efforts necessary to establish a plan for the development of Space Tug ground software. Included will be the advisability of transforming software modules from existing ground control systems, establishment of the basic data processing techniques, planning the use of existing ground system simulators and establishing ground program organizations and source strings

320-02-04-01-01 MISSION PHASE MANNING REQUIREMENTS

This task includes all efforts required to establish the types and quantity of personnel required to support Space Tug flight control and flight support activities. It will include an analysis of the mission density, the overlap

between adjacent modules in the mission structure and will establish the control and support necessary to accomplish the Space Tug missions with a minimum loss of productive man hours

320-01-02-01-03 COMPUTER UTILIZATION PLAN

This task includes all efforts required to develop and enforce a plan to maximize the utilization of the computational facility incorporated in the Tug ground control complex This will include a pre-emption hierarchy, mission planning schedule, mission operation schedule, batch processing schedule, etc.

320-01-02-01-04 MAINTENANCE SCHEDULE

This task establishes the housekeeping and periodic maintenance requirements of the control center and associated equipments. This task includes the contracting for, and administration of, specific external maintenance of the data system, plant environmental control mechanisms, and janitorial services. Periodic and specific maintenance of the flight control and flight support console items will be conducted by the permanent party flight support staff.

320-01-02-01-05 HIRE CONTROL AND SUPPORT STAFF

This task includes all efforts required to procure competent personnel to perform flight control tasks in the technical disciplines of propulsion, avionics, networks, communication, guidance, dynamics, data selection, television, and docking. It also includes the efforts required to hire flight support personnel in the technical disciplines of facility supervisor, data systems, maintenance operations and software support

320-10-02-03 CONSOLE ORGANIZATION

This task includes all efforts necessary to establish the requirements for location of console display and control devices to the satisfaction of the console operating personnel

320-10-02-01 DESIGN NETWORK INTERFACE

This task includes the engineering effort necessary to establish the interface with the data acquisition network. It specifically includes telemetry decommutation and special processing, command processing and television processing requirements. The output of this task will be the operational requirements for a network interface systems design which will include suggested hardware items

320-15-03-01 ESTIMATE GROUND SOFTWARE SIZE

This task analyzes the equation defining document for ground software and establishes a lower boundary upon the data system memory size and central processor unit speed requirements. For maximum cost effectiveness this task must be completed prior to the selection of an operational data system.

320-02-04-02-01 SELECT OPERATIONAL DATA SYSTEM

This task includes all efforts required to establish the integrated requirements of an operational data system and takes into account the ground software size estimate, the computer utilization plan, and growth factors. This task also includes all procurement and purchase operations necessary in the buy of an operational data system, and the engineering of the data system configuration

320-07-04-01 INSTALL OPERATIONAL DATA SYSTEM

This task includes all efforts by the data system contractor to install diagnose and checkout the completed system installation. At the end of this task, the data processing system will be on-line and operational ready to support future data processing activities.

320-06-06-01 SIZE FACILITY/DESIGN PHYSICAL PLANT

Prior to beginning this task, the operational data system will have been selected, the network interface design will have been completed and equipment selected, and the console equipment designed and ordered. This task includes the architectural design of the facility.

320-06-06-02 CONSTRUCT PHYSICAL PLANT

This task includes the efforts involved by a building contractor to perform site preparation, construction of a physical plant, environmental control and electrical installations on the structure.

320-07-04-02 INSTALL OPERATIONAL CONSOLES

This task includes the installation of the console hardware and associated interface equipments This task presumes that the consoles will be delivered to the finished physical plant by a vendor and then will be installed by flight support technicians.

320-15-02-02-01 EQUATION DEFINING DOCUMENT - EXECUTIVE/PLANNING SOFTWARE

This task includes those efforts in the definition and analysis leading to the development of the equations and algorithms to be utilized in the fundamental Space Tug ground programs

320-02-04-01-04 VALIDATION TEST REQUIREMENTS - FUNDAMENTAL TUG GROUND REQUIREMENTS

This task includes the establishment of proof-of-performance parameters for the software which is fundamental to the Space Tug operations. This task establishes the vital criteria against which the program performance is to be evaluated, and should be conducted independently of the Equation Definition generation.

320-15-02-03-01 PROGRAM GROUND PLANNING AND EXECUTIVE ROUTINES

This task depends on the generation of an adequate Equation Defining Document at a prior time, and includes the programming of all fundamental routines.

320-15-02-04-01 VERIFY EXECUTIVE AND PLANNING SOFTWARE

This task verifies that the intent of the Equation Defining Document has been implemented in the developed programs by testing the coded program under critical operational situations and includes the development of any special tools or simulators necessary in the accomplishment of this task

320-01-02-01-06 OBTAIN SPACE TUG SYSTEM CHARACTERISTICS

This task includes all efforts necessary to acquire catalog, define and analyze the operational characteristics of the Space Tug system. The output of this task is utilized in the development of flight controller display designs, network telemetry and updata interface system design and as primary input into the determination of operational failure modes

320-02-01-02 TUG MISSION CHARACTERISTICS

This task accepts the output on the master launch schedule analysis task and operates on that output to determine the specific characteristics of all defined Space Tug missions. The output of this task is utilized in the determination of mission phase manning requirements, definition of Space Tug operator certification (and criteria for certification), a computer utilization plan for the Space Tug portion of the Shuttle era and the associated maintenance schedule

320-15-01-02-01 EQUATION DEFINING DOCUMENT - SPACE TUG FLIGHT PROGRAM

This task includes basic conceptual work on the requirements for flight software, customer support and flight software definition, definitions of equations pertaining to vehicle dynamics, a design of algorith techniques and the associated simulation equipments, the generation of a program requirements document known as the Equation Defining Document (EDD), control of requirements, performance of software implementation studies, analysis of sample calculations, definition of flight control functional interfaces, definition of hardware interfaces, and miscellaneous preliminary analysis.

320-15-02-02-02 <u>TUG DOWN DATA/UP DATA AND DOCKING GROUND SOFTWARE</u>

This task includes all efforts required to create an Equation Defining Document (EDD) for those ground software modules which are specifically oriented to the Space Tug. The output of this task is an Equation Defining Document against which the ground Tug-peculiar software will be programmed.

320-02-04-01-05 <u>TUG GROUND VALIDATION TEST REQUIREMENTS</u>

This task includes all efforts required to establish the criteria for acceptance or rejection of Space Tug peculiar ground software. This task is performed independently of the programming effort and is specifically to establish proof-of-performance standards against which the program will be judged.

320-02-01-03 <u>DETERMINE TUG FAILURE MODES</u>

After the Space Tug system characteristics have been obtained, categorized and defined, the systems will be analyzed for high probability failure modes. The output of this task will be a list of potential failures, which can impact the operational performance of the vehicle. Failures of a cosmetic nature will not be considered. The output of this task is a list of high probability failure modes which will then be analyzed for the overall mission effect of that failure.

320-10-02-03 <u>TUG DISPLAY FORMAT DESIGN</u>

This task includes all efforts required to establish the organization, display format and engineering units for flight control and flight support personnel digital TV presentation. This task also includes all efforts directed toward the definition of the special processing requirements, remote site and control center logical operations, limit sensing, event light triggering, etc.

320-10-01-02 <u>TUG MISSION FAILURE EFFECTS ANALYSIS</u>

Once the Space Tug failure modes have been identified and categorized, the occurance of these failures at various points in the flight must be evaluated for overall mission effect. The output of this task will be a series of scenarios against which pre-thought decisions may be constructed

320-05-02-03-03 <u>DESIGN TUG MISSION SIMULATION</u>

This task includes all efforts required to integrate the results of the Space Tug procedures and rules, the optimum and abort mission timelines, and operator training criteria into a Tug mission specific simulation design. This task will be accomplished both in the DDT&E phase and in the recurring phase of the Space Tug program. A specific simulation design will be formulated for each mission. The flight controller and flight support personnel will be trained against the mission specific simulation in

preparation for their operational roles. The output of this task is a set of malfunctions, predicted responses and operator performance evaluation criteria

320-10-01-03 ANALYZE TUG COMPONENT CHARACTERISTICS

This task includes all efforts required to assemble basic operational information describing the characteristics of the operationally significant components of the Tug vehicle. The output of this task is a compendium of nominal operational performance, characteristic performance curves, expectations of behavior, etc This output will be utilized in the preparation of training material and reference handbook.

320-05-02-03-01 TUG TRAINING REQUIREMENTS, EVALUATION CRITERIA AND SIMULATION SCHEDULE

This task accepts as inputs the Space Tug console position guidelines, operator certification criteria, procedures and mission rules and from that information creates a requirement for training criteria against which successful training is judged, a definition of kind and content of simulations and a schedule for classroom and simulation training for a particular mission. This task is a recurring task.

320-10-01-04-01 PREPARE TUG SYSTEM HANDBOOK

This task includes all efforts required to generate simplified schematic diagrams, simplified interface connections, a summary of component characteristics, prediction of mission events and performance curves, and inherent Space Tug constraints and limitations.

320-10-01-04-02 PUBLISH AND UPDATE SPACE TUG SYSTEM HANDBOOK

The basic publication of a Space Tug system handbook will incorporate the information prepared for that purpose under one cover. The updating of a system handbook will be on a by-mission, and as required, basis, and thus, is an iterative task Major updates and changes to the Space Tug baseline design must be incorporated into the systems handbook prior to the utilization of that vehicle for a mission.

320-05-02-03-02 DEVELOP SPACE TUG TRAINING MATERIAL

This task includes the development and preparation of all materials required for classroom training of flight controllers and flight support personnel. This includes text books, handouts, view graphs, reference material, etc.

320-05-02-03-04 SPACE TUG CLASSROOM TRAINING

This task includes the instructor's time, student's time, and the facilities required for conducting classroom training in the characteristics of a Space Tug vehicle, the mission and support networks. Training will be conducted by flight control and flight support personnel in addition to their normal operational tasks.

320-10-01-05-03 SPACE TUG NETWORK DATA HANDLING REQUIREMENTS

This task includes all efforts required to produce a document levying specific data handling, processing, and special processing requirements on the supporting network. This includes both updata and downdata processing.

320-10-01-05-05 TUG NETWORK DATA VALIDATION PROCEDURES

This task includes all efforts required to establish proof-of-performance criteria for the acceptance test of Tug-peculiar ground software.

320-10-03-02 SPACE TUG NETWORK VALIDATION TESTS

This task includes all efforts required to conduct tests of the network handling of Space Tug peculiar software, including the providing of vehicle simulation tapes to remote sites of the ground data acqusition network, providing the procedures to remote operators, and providing personnel to conduct these tests.

320-15-02-03-02 PROGRAM SPACE TUG DOWN DATA, UP DATA AND SIMULATION SYSTEM

This task includes all efforts required to design an overall software system based on execution rates, input/output requirements, and response restrictions; design and develop Tug specific program modules, generating a detailed software design document, participation in design reviews, perform software integration testing, participate in change reviews and update software, provide configuration control and perform program generation, delivery and validation.

320-15-01-02-02 PROGRAM TUG FLIGHT SOFTWARE

This task includes all efforts required to develop pre-flight and flight software to satisfy baseline requirements. Included are performance of overall software system design based on execution rates, input/output requirements, and response time restrictions, design and develop executive and application program modules, generate detailed software design documentation; participate in design reviews, perform systematic integration testing of software, update software as a result of change activity, participate in configuration control, perform program delivery generation and validation, and provide customer support as required

320-15-02-04-02 VERIFY TUG DOWN DATA, UPDATA AND SIMULATION PROGRAMMING

This task includes all activities involved to insure, thru systematic testing by a independent functional area, that the Tug peculiar ground software satisfies all requirements levied upon it by the equation definition document. This includes analysis of software requirements to insure accuracy, adequacy, and completeness, generation of a detailed testing plan, performance of systematic tests utilizing interpretive simulators, analysis of software listings, analysis of hardware/software compatibility and validation of all changes made to the basic software package

320-02-04-01-02 <u>TUG CONSOLE POSITION GUIDELINES</u>

This task includes all activities required to establish generic position responsibilities as a function of console and technical discipline This activity is based upon the mission phase manning requirements and the output is utilized as one input to the mission simulation design and to the Space Tug requirements criteria, simulation and scheduled tasks. The output of this task establishes the organizational reporting tree authority invested in the greater positions and both technical and hierarchial relationships.

320-02-04-03-01 <u>TUG MISSION PLANNING AND OPTIMIZATION</u>

This task is iterative and includes the basic design of trajectory, timing of burns, and error propagation analysis leading to the design of the mission flight plan This task will be performed on the operational computer utilizing software specially developed for the purpose. The output of this task, and the output from the associated Space Tug abort planning task are utilized to establish the mission specific deviations from the Space Tug flight program baseline, and to provide an input to the mission specific simulation development.

320-10-01-01 <u>DEVELOP TUG PROCEDURES AND RULES</u>

The specific rules and procedures utilized during the mission will consists of a fundamental set of procedures and rules which are applicable across all Tug missions, and a mission specific set of rules and procedures. The output of this task is a document containing all predefined mission decisions, a document containing basic step-by-step implementation procedures, a set of predefined contingency procedures and a vehicle command listing.

320-02-04-03-02 <u>TUG ABORT PLANNING</u>

After the basic mission planning and optimization has been completed, certain off-nominal malfunction, abort and contingency conditions must be investigated and contingency operational procedures developed to handle those situations. This task utilizes special software programmed into the operational computer system and is iterated for each mission. The output of this task includes alternative mission definitions, abort profiles, and degraded mission plans This task is conducted roughly in parallel with the development of Tug procedures and mission rules in order that cross feed between the abort planning and contingency operational planning may take place.

320-01-02-01-08 <u>SPACE TUG INTERAGENCY COORDINATION</u>

This task includes all efforts required to establish mutual agreements with DoD and NASA centers supporting Space Tug mission operations This includes the coordination of program support requirement and ground support planning.

320-15-01-02-03 <u>SPACE TUG FLIGHT PROGRAM VERIFICATION</u>

The objective of program verification is to insure, thru systematic testing by a independent functional area, that the flight software satisfies all requirements levied on it by the Equation Defining Document. To accomplish this objective the following activities are performed analysis of software requirements, generation of a detailed testing plan, performance of systematic tests, analysis of software listings, comparison of flight software derived results with independently generated results, analysis of hardware/software compatibility, reverification of all changes made to the software and generation of documented test results.

320-01-02-01-07 <u>PREPARE TUG INTERAGENCY DOCUMENTATION</u>

This task includes all efforts required to prepare interagency and inter-center coordination documents. A ground support plan and documents which levy requirements on other government agencies or other NASA centers. The output of this task is required for the interagency coordination task

320-15-02-05-01 <u>PROGRAM TUG MISSION SIMULATION</u>

This task includes all efforts required to modify the baseline Tug simulator to incorporate mission specific profiles and contingency cases This task accepts as inputs the output from the Space Tug mission planning and optimization task, and the Space Tug abort planning task, as well as outputs from Space Tug basic simulation design. This task is iterative and must be repeated for each flight. This task is in a sense a mission specific simulation application module.

320-15-01-03-01 <u>TUG MISSION SPECIFIC EQUATION DEFINING DOCUMENT (EDD)</u>

This task includes all efforts required to modify the definition of the baseline Space Tug flight program to incorporate mission specific pecularities. This task is iterative and must be repeated prior to each flight

320-15-01-03-02 <u>TUG MISSION SPECIFIC PROGRAMMING</u>

This task develops the "application module" which incorporates the specific deviations from the baseline program required by the following Space Tug mission. This task is iterative and must be repeated prior to each flight.

320-15-01-03-03 <u>TUG MISSION PROGRAM VERIFICATION</u>

This task includes efforts necessary to analyze flight program implementation of the equation defining document for this "application module". The task includes generation of a detailed testing plan to insure that all requirements are satisfied, the performance of systematic tests, and generation of a test results document.

Table 10.1 2-2 Space Tug Operational Element Dictionary (Continued)

320-05-02-03-05 TUG MISSION SIMULATION TRAINING

This task includes the simulation of the specific Space Tug mission for nominal and contingency performance cases where in the flight support personnel conduct the simulation and the flight control personnel are judged on their ability to respond to contingency situations and to recognize nominal vehicle performance This task is iterative and must be repeated prior to each flight

320-10-04 CONDUCT SPACE TUG MISSION OPERATIONS

This task includes all efforts necessary to provide control and support to the Space Tug vehicle in prelaunch, orbital operations, placement, retrieval and landing phases. This task requires the total attention of the flight control team, the flight support team, and other personnel This task is the culmination of all prior efforts.

320-02-04-05-01 SPACE TUG POST MISSION REPORTS

This task includes all efforts required to generate three post mission reports. An evaluation and critique report prepared by the flight controllers which define the performance of the vehicle as viewed from the position of a real time console operator. A maintenance interface report prepared by the flight control personnel which summarizes the observations made in real time which imply maintenance requirements against the flight stage. This report is forwarded to the launch center for incorporation in the Specific Vehicle Maintenance Plan. The third report is the maintenance and operations interface report which evaluates the performance of the data gathering and tracking network during the mission

320-02-04-01-03 DEFINE TUG OPERATOR CERTIFICATION CRITERIA

This task includes all efforts required to analyze the functions of the consoles and to establish appraisal criteria by which the operator's performance may be evaluated. As with all real time operations, console operators must demonstrate the ability to perform well under stress. This task analyses the stress situations which the operator will face and establishes the criteria by which the operator's performance and technical adequacy are to be judged.

10.2 COMPARISON OF SPACE TUG AND IUS OPERATIONAL ELEMENTS

The work breakdown structures developed for IUS and Space Tug programs are compared in Table 10 2 0-1 The columns "C", "TU", "IU" and "M" designate the WBS elements to be "common" (or very close), "Tug Unique", "IUS Unique" or "Modifiable"

Each line item resulting in a "product" from both work breakdown structures is presented and an assessment made as to which category that line item would fit in an integrated program.

Explanations of the categorizations are supplied in the "Comments" field.

Basically, if a WBS line item is dependent upon factors outside the vehicle design sphere of influence, that line item is judged to be common to both IUS and Space Tug programs. On the other hand, if the WBS line item is dependent upon vehicle design, it is judged to be "IUS Unique" or "Space Tug Unique" "Modifiable" WBS line items are those which are initiated on the IUS program and phase over into the Space Tug program with some changes incorporated. Such items typically involve combinations of vehicle and external influences.

Table 10 2 0-1 Comparison of Space Tug and IUS Operational Elements

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
02-01-01	Master Launch Schedule Analysis	✓				This task may be shared by enlarging the scope of work - no unique factors.
01-02-01-01	Contract Software Development	✓				Mission timing and common utilization of data processing equipment make combining of software under one contractor attractively cost-effective
01-02-01-02	Plan Facility Utilization	✓				A single facility for both IUS and Tug mission control makes this a common task
15-01-01	Plan Flight Software Development	✓				Total IUS/Tug program cost can be minimized by integrating flight software development techniques, simulator, etc
15-02-01	Plan Ground Software Development	✓				Ground software will be driven by 1) IUS TM and CMD configuration, 2) Tug TM and CMD configuration, and 3) Ground system (network) configuration A unified plan will save double development costs for 3)
02-04-01-01	Mission Phase Manning Requirements	✓				Common disciplines are required, although mission structure may be significantly different This task can be combined and enlarged to include cross-training
01-02-01-03	Computer Utilization Plan	✓				Basic ground rules for computer utilization should apply to both programs

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Table 10.2.0-1 Comparison of Space Tug and IUS Operational Elements (Continued)

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
01-02-01-04	Maintenance Schedule	√			√	General maintenance policy will be a shared task. Maintenance of Tug-unique hardware (e i , television equipments) will require modification of the plan.
01-02-01-05	Hire Control and Support Staff	√				The same staff should be utilized by both IUS and Space Tug programs.
10-02-02	Console Organization	√				Console organization should be frozen early and carried through Tug
10-02-01	Design Network Interface	√			√	Equipment selected should be sufficiently flexible to encompass both IUS and Space Tug interface constraints.
15-03-01	Estimate Ground Software Size	√				This task must size for the maximum memory and speed load on the Data Processing system Thus must analyze both IUS and Tug programs
02-04-02-01	Select Operational Data System	√				The data processing system should be common to both programs.
07-04-01	Install Operational Data System	√				Same as above
06-06-01	Size Facility/Design Physical Plant	√				The physical plant should be designed to incorporate both program requirements without subsequent modification.
06-06-02	Construct Physical Plant	√				A single plant construction is desirable and cost-effective

Table 10 2 0-1. Comparison of Space Tug and IUS Operational Elements (Continued)

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
07-04-02	Install Operational Consoles	√				Consoles should be flexible enough to incorporate both IUS and Tug requirements with only minor modification
15-02-02-01	Equation Defining Document Executive/Tracking/Planning Software	√		√		The functions of the executive and mission planning software are independent of the flight vehicle Tracking is IUS-peculiar.
02-04-01-04	Validation Test Requirements Fundamental IUS [Tug] Ground Programs	√				This task establishes test requirements against common software and thus may be merged between both programs
10-01-05-01	Define Ground Network Tracking Requirements			√		Tracking will be an IUS function. Space Tug navigation will be autonomous
10-01-05-02	Network Tracking Validation Procedures			√		Procedures to test the tracking function are required
10-03-01	Network Tracking Validation Tests			√		The test is unique to the IUS program.
15-02-03-01	Program Ground Tracking, Planning and Executive Routines	√		√		This program implements the software which will be common to both IUS and Space Tug and the IUS tracking software
15-02-04-01	Verify Executive, Tracking and Planning Software	√		√		This task verifies the common aspects of the ground software and the IUS-peculiar tracking software

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Table 10.2.0-1. Comparison of Space Tug and IUS Operational Elements (Continued)

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
01-02-01-06	Obtain the IUS [Space Tug] System Characteristics		✓	✓		These tasks are independent, but both must be accomplished prior to the design of common network equipment and common console utilization
02-01-02	IUS [Tug] Mission Characterization		✓	✓		These tasks are independent, but both must be accomplished prior to major planning activities
15-01-02-01	Equation Defining Document IUS [Space Tug] Flight Program		✓	✓		All tasks relative to flight software design, development, programming and verification are vehicle - driven
15-02-02-02	IUS [Tug] Downdata/Updata/ [Docking] and Simulation Ground		✓	✓		These tasks are vehicle updata, downdata and configuration dependent
02-04-01-05	IUS [Tug] Ground Validation Test Requirements		✓	✓		These tasks are vehicle updata, downdata and configuration dependent
02-01-03	Determine IUS [Tug] Failure Modes		✓	✓		These tasks are vehicle configuration dependent
10-02-03	IUS [Tug] Display Format Design		✓	✓	✓	These tasks are vehicle updata, downdata and configuration dependent except in the flight dynamics discipline
10-01-02	IUS [Tug] Mission Failure Effects Analysis		✓	✓		These tasks are vehicle and mission configuration dependent

Table 10.2.0-1 Comparison of Space Tug and IUS Operational Elements (Continued)

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
05-02-03-03	Design IUS [Tug] Mission Simulation		✓	✓		These tasks are vehicle and mission configuration dependent.
10-01-03	Analyze IUS [Tug] Component Characteristics		✓	✓		These tasks are vehicle configuration dependent
05-02-03-01	IUS [Tug] Training Requirements, Evaluation Criteria and Simulation Schedule	✓	✓	✓		These tasks are vehicle and mission configuration dependent, but have common underlying human factor considerations
10-01-04-01	Prepare IUS [Tug] System Handbook		✓	✓		These tasks are vehicle configuration and performance dependent.
10-01-04-02	Publish and Update IUS [Tug] System Handbook		✓	✓		These tasks are vehicle configuration and performance dependent.
05-02-03-02	Develop IUS [Space Tug] Training Material		✓	✓		These tasks are vehicle downdata, updata, configuration and mission dependent.
05-02-03-04	IUS [Space Tug] Classroom Training		✓	✓		These tasks are vehicle downdata, updata, configuration and mission dependent
10-01-05-03	IUS [Space Tug] Network Data Handling Requirements		✓	✓		These tasks are vehicle updata and downdata dependent.
10-01-05-04	IUS [Tug] Network Data Validation Procedures		✓	✓		These tasks are vehicle updata and downdata dependent
10-03-02	IUS [Space Tug] Network Validation Tests		✓	✓		These tasks are vehicle updata and downdata dependent.

Table 10.2.0-1. Comparison of Space Tug and IUS Operational Elements (Continued)

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
15-02-03-02	Program IUS [Space Tug] Downdata/ Updata/[Docking]/Simulation System		✓	✓		These tasks are vehicle updata, downdata and configuration dependent.
15-02-04-02	Verify IUS [Tug] Downdata/Updata/ [Docking]/Simulation Programs		✓	✓		These tasks are vehicle updata, downdata and configuration dependent.
02-04-01-02	IUS [Tug] Console Position Guide- lines				✓	This task will be executed once for the IUS program, then modified for Space Tug implementation, based upon IUS experience.
02-04-03-01	IUS [Tug] Mission Planning and Optimization		✓	✓		This task is unique for each mission flown by both IUS and Tug.
10-01-01	Develop IUS [Tug] Procedures and Rules		✓	✓		These tasks are vehicle and mission dependent.
02-04-03-02	IUS [Tug] Abort Planning		✓	✓		This task is unique for each mission.
01-02-01-08	IUS [Space Tug] Interagency Coordination	✓	✓	✓		This task continues from IUS through Space Tug operations and involves program support documentation
15-01-02-03	IUS [Space Tug] Flight Program Verification		✓	✓		This task is vehicle and mission dependent
01-02-01-07	Prepare IUS [Tug] Interagency Documentation	✓	✓	✓		This task continues from IUS through Space Tug operations and involves program support documentation.
15-02-05-01	Program IUS [Tug] Mission Simulation		✓	✓		This task is unique for each mission flown by both IUS and Tug

Table 10.2.0-1 Comparison of Space Tug and IUS Operaional Elements (Continued)

WBS 320- OR XXX-	TITLE	C	TU	IU	M	COMMENTS
15-01-03-01	IUS [Tug] Mission Specific Equation Defining Document (EDD)		✓	✓		This task is unique for each mission flown by both IUS and Tug
15-01-03-02	IUS [Tug] Mission Specific Programming		✓	✓		This task is unique for each mission flown by both IUS and Tug.
15-01-03-03	IUS [Tug] Mission Program Verification		✓	✓		This task is unique for each mission flown by both IUS and Tug
05-02-03-05	IUS [Tug] Mission Simulation Training		✓	✓		This task is unique for each mission flown by both IUS and Tug
10-04	Conduct IUS [Space Tug] Mission Operations		✓	✓		This task is unique for each mission flown by both IUS and Tug.
02-04-05-01	IUS [Space Tug] Post Mission Reports		✓	✓		This task is unique for each mission flown by both IUS and Tug.
02-04-01-03	Define IUS [Tug] Operation Certification Criteria	✓	✓	✓		This task is mission and vehicle dependent, but also involves underlying common human factors considerations.

10.3 INTEGRATED SPACE TUG/IUS OPERATIONAL ELEMENTS

Table 10 3.0-1 presents the composite integrated Space Tug/IUS work breakdown structure Where common WBS elements were found, the integrated structure retains the "320-" designation, since Space Tug is to be the long-duration surviving program. Similarly, the higher elements in the structure (combinations of "products") retain the "320-" prefix

Table 10.3 0-2 presents the modified WBS dictionary for the composite Space Tug/IUS program

Table 10.3.0-1. Composite Integrated Space Tug/IUS Work Breakdown Structure WBS Identification Number Sequence

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320	SPACE TUG PROJECT	3
320-01	Project Management	4
320-01-01	Cost/Performance Management	5
320-01-01-01	Cost Control System	5
320-01-01-02	Schedule Control System	6
320-01-02	Project Direction	5
320-01-02-01	Development Management	6
320-01-02-01-01	Contract Software Development	7
320-01-02-01-02	Plan Facility Utilization	7
320-01-02-01-03	Computer Utilization Plan	7
320-01-02-01-04	Maintenance Schedule	7
320-01-02-01-05	Hire Control and Support Staff	7
320-01-02-01-06	Obtain Space Tug System Characteristics	7
320-01-02-01-07	Prepare Tug Interagency Documents	7
320-01-02-01-08	Tug Interagency Coordination	7
XXX-01-02-01-06	Obtain IUS System Characteristics	7
XXX-01-02-01-07	Prepare IUS Interagency Documents	7
XXX-01-02-01-08	IUS Interagency Coordination	7
320-01-02-02	Quality Management	6
320-01-02-03	Logistics Management	6
320-01-02-04	Engineering Administration	6
320-01-03	Information Management	6
320-02	Systems Engineering	4
320-02-01	IUS/Tug Systems Engineering	5
320-02-01-01	Master Launch Schedule Analysis	6
320-02-01-02	Tug Mission Characterization	6
320-02-01-03	Determine Tug Failure Modes	6
XXX-02-01-02	IUS Mission Characterization	6
XXX-02-01-03	Determine IUS Failure Modes	6
320-02-02	Shuttle Interface	5
320-02-03	Payload Interface	5
320-02-04	Sustaining Engineering	5
320-02-04-01	Flight Control Engineering	6
320-02-04-01-01	Mission Phase Manning Requirements	7
320-02-04-01-02	Tug Console Position Guidelines	7
320-02-04-01-03	Define Tug Operator Certification/Criteria	7
320-02-04-01-04	Common Ground Software Validation Test Requirements	7
320-02-04-01-05	Tug Ground Validation Test Requirements	7
XXX-02-04-01-05	IUS Ground Validation Test Requirements	7
XXX-02-04-01-02	IUS Console Position Guidelines	7
XXX-02-04-01-03	Define IUS Operator Certification/Criteria	7
320-02-04-02	Flight Support Engineering	6
320-02-04-02-01	Select Operational Data System	7

Table 10.3.0-1 Composite Integrated Space Tug/IUS Work Breakdown Structure WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-02-04-03	Mission Engineering	6
320-02-04-03-01	Tug Mission Planning and Optimization	7
320-02-04-03-02	Tug Abort Planning	7
XXX-02-04-03-01	IUS Mission Planning and Optimization	7
XXX-02-04-03-02	IUS Abort Planning	7
320-02-04-05	Mission Evaluation Engineering	6
320-02-04-05-01	Tug Post Mission Reports	7
XXX-02-04-05-01	IUS Post Mission Reports	7
320-03	Tug Vehicle Main Stage	4
320-05	Logistics	4
320-05-01	Transportation and Handling	5
320-05-02	Training	5
320-05-02-01	Simulators and Equipment	6
320-05-02-02	Ground Crew Training	6
320-05-02-03	Flight Operations Crew Training	6
320-05-02-03-01	Tug Training Requirement/Criteria/Simsked	7
320-05-02-03-02	Develop Tug Training Material	7
320-05-02-03-03	Design Tug Mission Simulation	7
320-05-02-03-04	Tug Classroom Training	7
320-05-02-03-05	Tug Mission Simulation Training	7
XXX-05-02-03-01	IUS Training Requirement/Criteria/Simsked	7
XXX-05-02-03-02	Develop IUS Training Material	7
XXX-05-02-03-03	Design IUS Mission Simulation	7
XXX-05-02-03-04	IUS Classroom Training	7
XXX-05-02-03-05	IUS Mission Simulation Training	7
320-06	Facilities	4
320-06-01	Manufacturing	5
320-06-02	Test	5
320-06-03	Maintenance and Refurbishment	5
320-06-04	ETR Launch	5
320-06-05	WTR Launch	5
320-06-06	Flight Operations Facility	5
320-06-06-01	Size Facility/Design Physical Plant	6
320-06-06-02	Construct Physical Plant	6
320-07	Ground Support Equipment (GSE)	4
320-07-01	Manufacturing and Test GSE	5
320-07-02	Eastern Test Range GSE	5
320-07-03	Western Test Range GSE	5
320-07-04	Flight Operations GSE	5
320-07-04-01	Install Operational Data System	6
320-07-04-02	Install Operational Consoles/Hardware	6
320-08	Vehicle Test	4
320-09	Launch Operations	4
320-10	Flight Operations	4
320-10-01	Mission Planning and Documentation	5
320-10-01-01	Develop Tug Procedures and Rules	6
XXX-10-01-01	Develop IUS Procedures and Rules	6
320-10-01-02	Tug Mission Failure Effects	6
XXX-10-01-02	IUS Mission Failure Effects	6
320-10-01-03	Analyze Tug Component Characteristics	6
XXX-10-01-03	Analyze IUS Component Characteristics	6

Table 10.3.0-1 Composite Integrated Space Tug/IUS Work Breakdown Structure WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-10-01-04	Flight Control Systems Handbook	6
320-10-01-04-01	Prepare Tug Systems Handbook	7
320-10-01-04-02	Publish/Update Tug Systems Handbook	7
XXX-10-01-04-01	Prepare IUS Systems Handbook	7
XXX-10-01-04-02	Publish/Update IUS Systems Handbook	7
320-10-01-05	Tug Network Interface Documentation	6
XXX-10-01-05-01	Define Network Tracking Requirements	7
XXX-10-01-05-02	Network Tracking Validation Procedures	7
320-10-01-05-03	Tug Network Data Handling Requirements	7
320-10-01-05-04	Tug Network Data Validation Procedures	7
XXX-10-01-05-03	IUS Network Data Handling Requirements	7
XXX-10-01-05-04	IUS Network Data Validation Procedures	7
320-10-02	Operational Preparations	5
320-10-02-01	Design Network Interface System	6
320-10-02-02	Console Organization	6
320-10-02-03	Tug Display Format Design	6
XXX-10-02-03	IUS Display Format Design	6
320-10-03	Mission Readiness Testing	5
XXX-10-03-01	Network Tracking Validation Tests	6
320-10-03-02	Tug Network Validation Tests	6
XXX-10-03-02	IUS Network Validation Tests	6
320-10-04	Conduct Tug Mission Operations	5
XXX-10-04	Conduct IUS Mission Operations	5
320-11	Refurbishment and Integration	4
320-15	Software	4
320-15-01	Flight Software	5
320-15-01-01	Plan Flight Software Development	6
320-15-01-02	Baseline Flight Program Development	6
320-15-01-02-01	EDD - Tug Flight Program	7
320-15-01-02-02	Program Tug Flight Software	7
320-15-01-02-03	Tug Flight Program Verification	7
XXX-15-01-02-01	EDD - IUS Flight Program	7
XXX-15-01-02-02	Program IUS Flight Software	7
XXX-15-01-02-03	IUS Flight Program Verification	7
320-15-01-03	Mission Specific Program Modification	6
320-15-01-03-01	Tug Mission Specific EDD	7
320-15-01-03-02	Tug Mission Specific Program	7
320-15-01-03-03	Tug Mission Program Verification	7
XXX-15-01-03-01	IUS Mission Specific EDD	7
XXX-15-01-03-02	IUS Mission Specific Program	7
XXX-15-01-03-03	IUS Mission Program Verification	7
320-15-02	Ground Software	5
320-15-02-01	Plan Ground Software Development	6
320-15-02-02	Equation Definition	6
320-15-02-02-01	EDD - Executive/Tracking/Planning	7
320-15-02-02-02	EDD - Tug Dndata/Updata/Docking/Sim	7
XXX-15-02-02-02	EDD - IUS Dndata/Updata/Sim	7
320-15-02-03	Programming	6

Table 10.3.0-1 Composite Integrated Space Tug/IUS Work Breakdown Structure WBS Identification Number Sequence (Continued)

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-15-02-03-01	Program Ground EX/TK/Planning SW	7
320-15-02-03-02	Program Tug Dndata/Updata/Docking/Sim	7
XXX-15-02-03-02	Program IUS Dndata/Updata/Sim	7
320-15-02-04	Program Verification	6
320-15-02-04-01	Verify Executive/TK/Planning SW	7
320-15-02-04-02	Verify Tug Dndata/Updata/Docking/Sim	7
XXX-15-02-04-02	Verify IUS Dndata/Updata/Sim	7
320-15-02-05	Mission Specific Simulation	6
320-15-02-05-01	Program Tug Mission Simulation	7
XXX-15-02-05-01	Program IUS Mission Simulation	7
320-15-03	Computer Selection Support	5
320-15-03-01	Estimate Ground Software Size	6
320-16	Orbiter Interface	4

Table 10 3 0-2 WBS Definitions

320 SPACE TUG PROJECT

This element summarizes the direct and indirect (G&A and burden) effort to provide hardware, software, services, and facilities that are required to develop, produce, operate, and maintain a Space Tug Project, including the associated Tug/Shuttle interfaces

320-01 PROJECT MANAGEMENT

This element summarizes the management activities of planning, organizing, directing, coordinating, controlling and approval actions required to accomplish overall Space Tug Project objectives which are not associated with specific hardware elements

320-01-02 PROJECT DIRECTION

This element pertains to the continuous monitoring of all functional management disciplines to provide central direction and control of the overall project Included are the decision making for management, timely resolution of problem areas to meet established schedules, and overall surveillance of project progress and goals.

320-01-02-01 DEVELOPMENT MANAGEMENT

This element includes those tasks which require external contractual interfaces, interagency interfaces and inter-center interfaces to be accomplished It also includes direction of sensitive development tasks which require project level stature to insure proper execution

320-01-02-01-01 CONTRACT SOFTWARE DEVELOPMENT

This task includes all effort necessary to prepare a Statement of Work, evaluate proposals and provide financial, contracting and procurement support in order to place an outside contractor under contract for development of ground and flight software

320-01-02-01-02 PLAN FACILITY UTILIZATION

This task includes all efforts involved in establishing a coherent plan for the utilization of a Mission Control facility This will include such things as scheduling of activities, program sharing, office, canteen, technical support area and other generic requirements which impact facility design

320-01-02-01-03 COMPUTER UTILIZATION PLAN

This task includes all efforts required to develop and enforce a plan to maximize the utilization of the computational facility incorporated in the IUS/Tug ground control complex This will include a pre-emption hierarchy, mission planning schedule, mission operation schedule, batch processing schedule, etc

320-01-02-01-04 MAINTENANCE SCHEDULE

This task establishes the housekeeping and periodic maintenance requirements of the control center and associated equipments This task includes the contracting for, and administration of, specific external maintenance of the data system, plant environmental control mechanisms, and janitorial services. Periodic and specific maintenance of the flight control and flight support console items will be conducted by the permanent party flight support staff.

320-01-02-01-05 HIRE CONTROL AND SUPPORT STAFF

This task includes all efforts required to procure competent personnel to perform flight control tasks in the technical disciplines of propulsion, avionics, networks, communication, guidance, dynamics, data selection, television, and docking. It also includes the efforts required to hire flight support personnel in the technical disciplines of facility supervisor, data systems, maintenance operations and software support

320-01-02-01-06 OBTAIN SPACE TUG SYSTEM CHARACTERISTICS

This task includes all efforts necessary to acquire, catalog, define and analyze the operational characteristics of the Space Tug system The output of this task is utilized in the development of flight controller display designs, network telemetry and updata interface systems design, and as primary input into the determination of operational failure modes

XXX-01-02-01-06 OBTAIN IUS SYSTEM CHARACTERISTICS

This task includes all efforts necessary to acquire, catalog, define and analyze the operational characteristics of the IUS system. The output of this task is utilized in the development of flight controller display designs, network telemetry and updata interface system design, and as primary input into the determination of operational failure modes.

320-01-02-01-07 PREPARE TUG INTERAGENCY DOCUMENTATION

This task includes all efforts required to prepare interagency and intercenter coordination documents, a ground support plan and documents which levy requirements on other government agencies or other NASA centers The output of this task is required for the interagency coordination task.

320-01-02-01-08 SPACE TUG INTERAGENCY COORDINATION

This task includes all efforts required to establish mutual agreements with DoD and NASA centers supporting Space Tug mission operations. This includes the coordination of program support requirements and ground support planning

XXX-01-02-01-08 IUS INTERAGENCY COORDINATION

This task includes all efforts required to establish mutual agreements with DoD and NASA centers supporting the IUS mission operations This includes the coordination of program support requirement and ground support planning

320-01-02-01-09 SPACE TUG NETWORK RENTAL

This element includes the cost of purchasing network services (Telemetry Data, Command Data, Television Image) from the data support network

XXX-01-02-01-09 IUS NETWORK RENTAL

This element includes the cost of purchasing network servcies (Telemetry Data, Command Data, Tracking Data) from the data support network

320-02 SYSTEMS ENGINEERING

This element summarizes the Space Tug systems engineering task of directing and controlling a totally integrated engineering effort, including requirements analysis and integration, system definition, system test definition, interfaces, safety, reliability, maintainability, configuration management, quality engineering, technology utilization and logistics support analysis

320-02-01 IUS/TUG SYSTEMS ENGINEERING

This element consists of the systems engineering and integration effort to design, develop, produce and test the Space Tug and associated Tug/Shuttle interfaces Included are analyses required to verify compatibility of designs with requirements, to meet mission model requirements, to control and direct the engineering activities, to assure proper Space Tug systems integration with both the Shuttle and spacecraft, and to make cost/performance tradeoffs Also included are engineering planning, studies, technology utilization, technical risk assessment, reliability engineering, safety engineering, quality control, configuration requirements analysis, and associated support required to perform the Tug systems engineering task Logistics planning and management are also included

320-02-01-01 MASTER LAUNCH SCHEDULE ANALYSIS

The master Launch Schedule will be analyzed to determine the type, spacing, and frequency of both IUS and Space Tug flight This task will establish the range of mission types, trajectories, payload accommodations and control facility utilization requirements across the IUS/Space Tug operational period This task is a predecessor to the establishment of Tug mission characteristics, IUS mission characteristics and control facility utilization planning

320-02-01-02 TUG MISSION CHARACTERIZATION

This task accepts the output of the master launch schedule analysis task and operates on that output in order to determine the specific characteristics of all defined Space Tug missions The output of this task is utilized in the determination of mission phase manning requirements, definition of Space Tug operator certification (and criteria for certification), a computer utilization plan for the Space Tug portion of the Shuttle era and the associated maintenance schedule

XXX-02-01-02 IUS MISSION CHARACTERIZATION

This task accepts the output of the master launch schedule analysis tasks and operates on that output in order to determine the specific characteristics

of all defined IUS missions The output of this task is utilized in the determination of mission phase manning requirements, definition of IUS operator certification (and criteria for certification), a computer utilization plan for the IUS portion of the Shuttle era and the associated maintenance schedule

320-02-01-03 DETERMINE TUG FAILURE MODES

After the Space Tug system characteristics have been obtained, categorized and defined, the systems will be analyzed for high probability failure modes The output of this task will be a list of potential failures, which can impact the operational performance of the vehicle Failures of a cosmetic nature will not be considered The output of this task is a list of high probability failure modes which will then be analyzed for the overall mission effect of that failure

XXX-02-01-03 DETERMINE IUS FAILURE MODES

After the IUS system characteristics have been obtained, categorized and defined, the systems will be analyzed for high-probability failure modes. The output of this task will be a list of potential failures which can impact the operational performance of the vehicle. Failures of a cosmetic nature will not be considered The output of this task is a list of high probability failure modes which will then be analyzed for the overall mission effort of that failure

320-02-04 SUSTAINING ENGINEERING

This element consists of sustaining engineering effort required for the Space Tug and associated Tug/Shuttle interfaces after the completed, assembled Tug and interface subsystems have been checked out for full flight certification and delivered A principal effort includes normal product improvement and engineering changes that may occur as a result of user recommendations and/or operational experience Also included are in-plant engineering liaison support of operational activities and the sustaining engineering support required during the operations phase. Activities would include further allocation of performance requirements for the vehicle into subsystem requirements, evaluation of vehicle and GSE performance, maintainability analysis, etc Excluded are those activities that pertain to major hardware modification required to meet new performance specifications

320-02-04-01 FLIGHT CONTROL ENGINEERING

This task includes all efforts required to provide real-time assessment of systems status, formulation and issuance of command actions, pre-mission preparation, training and operator certification.

320-02-04-01-01 MISSION PHASE MANNING REQUIREMENTS

This task includes all efforts required to establish the types and quantity of personnel required to support both IUS and Space Tug flight control and flight support activities. It will include an analysis of the mission density, the overlap between adjacent modules in the mission structure and will

establish the control and support personnel necessary to accomplish the IUS and Space Tug missions with a minimum loss of productive man hours This task will also include the plan for cross-training mission support personnel as the IUS phases into the Space Tug era

320-02-04-01-02 TUG CONSOLE POSITION GUIDELINES

This task includes all activities required to establish generic position responsibilities as a function of console and technical discipline This activity is based upon the mission phase manning requirements The output is utilized as one input to the mission simulation design and to the Space Tug requirements criteria, simulation and schedule tasks The output of this task establishes the organizational reporting tree and authority for both technical and hierarchial relationships.

XXX-02-04-01-02 IUS CONSOLE POSITION GUIDELINES

This task includes all activities required to establish generic position responsibilities as a function of console and technical discipline This activity is based upon the mission phase manning requirements The output is utilized as one input to the mission simulation design and to the IUS requirements criteria, simulation and schedule tasks The output of this task establishes the organizational reporting tree authority for both technical and hierarchial relationships.

320-02-04-01-03 DEFINE SPACE TUG OPERATOR CERTIFICATION/CRITERIA

This task includes all efforts required to analyze the functions of the consoles and to establish appraisal criteria by which the operator's performance may be evaluated As with all real time operations, console operators must demonstrate the ability to perform well under stress This task analyzes the stress situations which the operator will face and establishes the criteria by which the operator's performance and technical adequacy are to be judged

XXX-02-04-01-03 DEFINE IUS OPERATOR CERTIFICATION/CRITERIA

This task includes all efforts required to analyze the functions of the consoles and to establish appraisal criteria by which the operator's performance may be evaluated As with all real time operations, console operators must demonstrate the ability to perform well under stress. This task analyzes the stress situations which the operator will face and establishes the criteria by which the operator's performance and technical adequacy are to be judged

320-02-04-01-04 COMMON GROUND VALIDATION TEST REQUIREMENTS

This task includes the establishment of proof-of-performance parameters for the software which is common to both the IUS ground operations and the Space Tug operations This task establishes the vital criteria against which

the program performance is to be evaluated, and should be conducted independently of the Equation Definition generation

320-02-04-01-05 TUG GROUND VALIDATION TEST REQUIREMENTS

This task includes all efforts required to establish the criteria for acceptance or rejection of Space Tug peculiar ground software. This task is performed independently of the programming effort and is specifically to establish proof-of-performance standards against which the program will be judged.

XXX-02-01-05 IUS GROUND VALIDATION TEST REQUIREMENTS

This task includes all efforts required to establish the criteria for acceptance or rejection of IUS-peculiar ground software. This task is performed independently of the programming effort and is specifically to establish proof-of-performance standards against which the program will be judged.

320-02-04-02 FLIGHT SUPPORT ENGINEERING

This task includes all efforts required to provide real-time support to Flight Control personnel, maintain operational hardware in operable condition, provide network interface and alternate support capability.

320-02-04-02-01 SELECT OPERATIONAL DATA SYSTEM

This task includes all efforts required to establish the integrated requirements of an operational data system and takes into account the ground software size estimate, the computer utilization plan, and growth factors This task also includes all procurement and purchase operations necessary in the buy of an operational data system, and the engineering of the data system configuration

320-02-04-03 MISSION ENGINEERING

This task includes all efforts to plan and optimize the Space Tug or IUS trajectory under nominal mission and abort conditions

320-02-04-03-01 TUG MISSION PLANNING AND OPTIMIZATION

This task is iterative and includes the basic design of trajectory. timing of burns, and error propagation analysis leading to the design of the mission flight plan This task will be performed on the operational computer utilizing software specially developed for the purpose The output of this task, and the output from the associated Space Tug abort planning task are utilized to establish the mission specific deviations from the Space Tug flight program baseline, and to provide an input to the mission specific simulation development.

XXX-02-04-03-01 IUS MISSION PLANNING AND OPTIMIZATION

This task includes the basic design of trajectory, timing of burns, and error propagation analysis leading to the design of the mission flight plan This task will be performed on the operational computer utilizing software

specially developed for the purpose The output of this task, and the output from the associated IUS abort planning task are utilized to establish the mission specific deviations from the IUS flight program baseline, and to provide an input to the mission specific simulation development

320-02-04-03-02 TUG ABORT PLANNING

After the basic mission planning and optimization has been completed, certain off- nominal malfunction, abort and contingency conditions must be investigated and contingency operational procedures developed to handle those situations This task utilizes special software programmed into the operational computer system and is iterated for each mission The output of this task includes alternative mission definitions, abort profiles, and degraded mission plans This task is conducted roughly in parallel with the development of Tug procedures and mission rules in order that cross feed between the abort planning and contingency operational planning may take place

XXX-20-04-03-02 IUS ABORT PLANNING

After the basic mission planning and optimization has been completed, certain off-nominal malfunction, abort and contingency conditions must be investigated and contingency operational procedures developed to handle those situations This task utilizes special software programmed into the operational computer system and is iterated for each mission The output of this task includes alternative mission definitions, abort profiles, and degraded mission plans This task is conducted roughly in parallel with the development of IUS procedures and mission rules in order that cross-feed between the abort planning and contingency operational planning may take place.

320-02-04-05 MISSION EVALUATION ENGINEERING

This task includes all efforts required to evaluate vehicle performance-to-design analysis, and to provide comprehensive feed-back into the design modification and maintenance programs of the vehicles.

320-02-04-05-01 SPACE TUG POST MISSION REPORTS

This task includes all efforts required to generate three post mission reports an evaluation and critique report prepared by the flight controllers which define the performance of the vehicle as viewed from the position of a real time console operator, a maintenance interface report prepared by the flight control personnel which summarizes the observations made in real time which imply maintenance requirements against the flight stage, (this report is forwarded to the launch center for incorporation in the Specific Vehicle Maintenance Plan), a maintenance and operations interface report which evaluates the performance of the data gathering and tracking network during the mission

XXX-02-04-05-01 IUS POST MISSION REPORTS

This task includes all efforts required to generate two post mission reports an evaluation and critique report is prepared by the flight controllers which define the performance of the vehicle as viewed from the positions of a real

time console operator and a maintenance and operations interface report which evaluates the performance of the data gathering and tracking network during the mission

320-05 LOGISTICS

This element provides the effort to implement, operate, and maintain a logistics management for support of the Tug and Tug/Shuttle interfaces and related ground support equipment, including transportation, handling, factory warehousing, and inventories, systems orientation, and familiarization, training of ground and flight crew personnel and the design, development and manufacture of those distinctive end-items required specifically to meet the training objectives Included are operational maintenance trainers, cutaways, models and any facilities constructed or modified for training purposes.

320-05-02 TRAINING

This element consists of training services, training materials, training aids and training equipment required for Tug factory, technical, flight and ground crew training It includes instructor and student services, and the development and maintenance of lesson plans, study guides, training manuals, and training aids for classroom and trainer instruction in preparation for and during the Tug test and operations program phases

320-05-02-03 FLIGHT OPERATIONS CREW TRAINING

This element includes the cost of instruction, audio-visual teaching aids and accessories required to train the personnel to operate the Tug and equipment required to support flight operations at a flight operations center

320-05-02-03-01 TUG TRAINING REQUIREMENTS, EVALUATION CRITERIA AND SIMULATION SCHEDULE

This task accepts as inputs the Space Tug console position guidelines, operator certification criteria, procedures and mission rules and from that information creates a requirement for training criteria against which successful training is judged, a definition of kind and content of simulations and a schedule for classroom, and simulation training for a particular mission This task is a recurring task

XXX-05-02-03-01 IUS TRAINING REQUIREMENTS, EVALUATION CRITERIA AND SIMULATION SCHEDULE

This task accepts as input the IUS console position guidelines, operator certification criteria, procedures and mission rules and from that information creates a requirement for training criteria against which successful training is judged, definition of kind and content of simulations and a schedule for classroom, and simulation training for a particular mission. This task is a recurring task.

320-05-02-03-02 DEVELOP SPACE TUG TRAINING MATERIAL

This task includes the development and preparation of all materials required for classroom training of flight controllers and flight support personnel This includes text books, handouts, view graphs, reference material, etc

XXX-05-02-03-02 DEVELOP IUS TRAINING MATERIAL

This task includes the development and preparation of all materials required for classroom training of flight controllers and flight support personnel This includes text books, handouts, view graphs, reference material, etc

320-05-02-03-03 DESIGN TUG MISSION SIMULATION

This task includes all efforts required to integrate the results of the Space Tug procedures and rules, the optimum and abort mission timelines, and operator training criteria into a Tug mission specific simulation design This task will be accomplished both in the DDT&E phase and in the recurring phase of the Space Tug program A specific simulation design will be formulated for each mission The flight controller and flight support personnel will be trained against the mission specific simulation in preparation for their operational roles. the output of this task is a set of malfunctions, predicted responses and operator performance evaluation criteria

XXX-05-02-03-03 DESIGN IUS MISSION SIMULATION

This task includes all efforts required to integrate the results of the IUS procedures and rules, the optimum and abort mission timelines, and operator training criteria into an IUS mission specific simulation design This task will be accomplished both in the DDT&E phase and in the recurring phase of the IUS program A specific simulation design will be formulated for each mission The flight control and flight support personnel will be trained against the mission specific simulation in preparation for their operational roles. The output of this task is a set of malfunctions, predicted responses and operator performance evaluation criteria

320-05-02-03-04 SPACE TUG CLASSROOM TRAINING

This task includes the instructor's time, student's time, and the facilities required for conducting classroom training in the characteristics of a Space Tug vehicle, the mission, and support networks Training will be conducted by flight control and flight support personnel in addition to their normal operational tasks

XXX-05-02-03-04 IUS CLASSROOM TRAINING

This task includes the instructor's time, student's time, and the facilities required for conducting classroom training in the characteristics of an IUS vehicle, the mission, and support networks Training will be conducted by flight control and flight support personnel in addition to their normal operational tasks

320-05-02-03-05 TUG MISSION SIMULATION TRAINING

This task includes the simulation of the specific Space Tug mission for nominal and contingency performance cases wherein the flight support personnel conduct the simulation and the flight control personnel are judged on their ability to respond to contingency situations and to recognize nominal vehicle performance. This task is iterative and must be repeated prior to each flight

XXX-05-02-03-05 IUS MISSION SIMULATION TRAINING

This task includes the simulation of the specific IUS mission for nominal and contingency performance cases wherein the flight support personnel conduct the simulation and the flight control personnel are judged on their ability to respond to contingency situations and to recognize nominal vehicle performance This task is iterative and must be repeated prior to each flight.

320-06 FACILITIES

This element covers facilities (new or modification to existing) for manufacture, test, maintenance, refurbishment, and support of an operational program Note that the basic launch and operations facilities are charged to the Shuttle However, those facilities built specifically for Tug and Tug/Shuttle interfaces are included here This effort includes facilities planning, acquisition or modification, and maintenance Amortization of adequate existing facilities will not be included

320-06-06 FLIGHT OPERATIONS FACILITY

This element covers development of a new facility for flight control support of the IUS and Space Tug programs. This effort includes facility planning, acquisition, modification and maintenance

320-06-06-01 SIZE FACILITY/DESIGN PHYSICAL PLANT

Prior to beginning this task, the operational data system will have been selected, the network interface design will have been completed and equipment selected, and the console equipment designed and ordered This task includes the architectural design of the facility.

320-06-06-02 CONSTRUCT PHYSICAL PLANT

This task includes the effort involved by a building contractor to perform site preparation, construction of a physical plant, environmental control and electrical installations on the structure.

320-06-06-03 PLANT MAINTENANCE

This task includes all contracted services for the maintenance of the facility interior and exterior, including refuse, janitorial services, structural, electrical, mechanical and paint maintenance Also included are utility costs.

320-07 GROUND SUPPORT EQUIPMENT (GSE)

This element includes all GSE required for the Tug and Tug/Shuttle interface subsystems test and operations Included are all ground-based equipment required to support the ground test program and launch, recovery and maintenance phases during flight test operations and flight operations The GSE element includes design, fabrication, documentation, and qualification of Tug and Tug/Shuttle interface peculiar test and operational GSE. GSE items included are hardware, site activiation, and maintenance peculiar to interface ground operations for manufacturing and launch.

320-07-04 FLIGHT OPERATIONS GSE

This element includes all ground-based equipment required to support flight control of the Space Tug during both flight tests and operations This element also includes design, modification, fabrication, integration, documentation, and qualification of the site. Items included are hardware, site activiation, and maintenance

320-07-04-01 INSTALL OPERATIONAL DATA SYSTEM

This task includes all efforts by the data system contractor to install, diagnose and checkout the completed data system installation At the end of this task, the data processing system will be on-line and operational, ready to support future data processing activities

320-07-04-02 INSTALL OPERATIONAL CONSOLES

This task includes the installation of the console hardware and associated interface equipments This task presumes that the consoles will be delivered to the finished physical plant by a vendor and then will be installed by flight support technicians

320-07-04-03 DATA SYSTEM MAINTENANCE

This task includes contracted services for the maintenance, diagnosis and repair of the operational data system and associated peripheral equipment. This service is contracted on an annual basis

320-10 FLIGHT OPERATIONS

This element includes flight operations tasks and services directly related to the post-launch real-time operational control of the Space Tug and IUS vehicles These activities include mission planning and Documentation, Operational preparations, Flight Readiness Testing and Real-Time Flight Control

320-10-01 MISSION PLANNING AND DOCUMENTATION

This task includes efforts to develop and document mission rules and flight control procedures, analyze mission effects of system malfunction, analyse vehicle component characteristics, preparation and update of reference documents, documentation of requirements on and procedures for testing support network interface

320-10-01-01 DEVELOP TUG PROCEDURES AND RULES

The specific rules and procedures utilized during the mission will consist of a fundamental set of procedures and rules which are applicable across all Tug missions, and a mission specific set of rules and procedures. The output of this task is a document containing all predefined mission decisions, a document containing basic step-by-step implementation procedures, a set of predefined contingency procedures and a vehicle command listing

XXX-10-01-01 DEVELOP IUS PROCEDURES AND RULES

The specific rules and procedures utilized during the mission will consist of a fundamental set of procedures and rules which are applicable across all IUS missions, and a mission specific set of rules and procedures. The output of this task is a document containing all predefined mission decisions, a document containing basic step-by-step implementation procecures, a set of predefined contingency procedures and a vehicle command listing

XXX-10-01-02 IUS MISSION FAILURE EFFECTS ANALYSIS

Once the IUS failure modes have been identified and categorized, the occurrence of these failures at various points in the flight must be evaluated for overall mission effect The output of this task will be a series of scenarios against which pre-thought decisions may be constructed

320-10-01-02 TUG MISSION FAILURE EFFECTS ANALYSIS

Once the Space Tug failure modes have been identified and categorized, the occurrence of these failures at various points in the flight must be evaluated for overall mission effect The output of this task will be a series of scenarios against which pre-thought decisions may be constructed.

320-10-01-03 ANALYZE TUG COMPONENT CHARACTERISTICS

This task includes all efforts required to assemble basic operational information describing the characteristics of the operationally significant components of the Tug vehicle The output of this task is a compendium of nominal operational performance, characteristic performance curves, expectations of behavior, etc This output will be utilized in the preparation of training material and a reference handbook

XXX-10-01-03 ANALYZE IUS COMPONENT CHARACTERISTICS

This task includes all efforts required to assemble basic operational information describing the characteristics of the operationally significant components of the IUS vehicles. The output of this task is a compendium of nominal operational performance, characteristic performance curves, expectations of behavior, etc This output will be utilized in the preparation of training material and a reference handbook

320-10-01-04 FLIGHT CONTROL SYSTEMS HANDBOOK

This task includes the acquisition, assembly and preparation of Space Tug or IUS vehicle systems data in a form which is readily accessible to

real-time operational personnel This includes schematic diagrams, performance characteristics, component characteristics and inherent constraints and limitations on vehicle operations

320-10-01-04-01 PREPARE TUG SYSTEM HANDBOOK

This task includes all efforts required to generate simplified schematic diagrams, simplified interface connections, a summary of component characteristics, prediction of mission events and performance curves, and inherent Space Tug constraints and limitations

XXX-10-01-04-01 PREPARE IUS SYSTEM HANDBOOK

This task includes all efforts required to generate simplified schematic diagrams, simplified interface connections, a summary of component characteristics, prediction of mission events and performance curves, and inherent IUS constraints and limitations

320-10-01-04-02 PUBLISH AND UPDATE SPACE TUG SYSTEM HANDBOOK

The basic publication of a Space Tug system handbook will incorporate the information prepared for that purpose under one cover The updating of a system handbook will be on a by-mission, and as required, basis, and thus, is an iterative task Major updates and changes to the Space Tug baseline design must be incorporated into the systems handbook prior to the utilization of that vehicle for a mission.

XXX-10-01-04-02 PUBLISH AND UPDATE IUS SYSTEM HANDBOOK

The basic publication of a Space Tug system handbook will incorporate the information prepared for that purpose under one cover The updating of a system handbook will be on a by-mission, and as required, basis, and thus, is an iterative task. Major updates and changes to the IUS baseline design must be incorporated into the systems handbook prior to the utilization of that vehicle for a mission

320-10-01-05 NETWORK INTERFACE DOCUMENTATION

This element includes efforts required to establish performance requirements on the data network feeding the Flight Operations control center, and to generate proof-of-performance test procedures for the network

XXX-10-01-05-01 DEFINE GROUND NETWORK TRACKING REQUIREMENTS

This task includes those systems analyses, mission engineering, flight control and flight support efforts required to develop a checkout procedure which will exercise the tracking capabilities of the support network from the flight control and flight support consoles in the Mission Control Center The output of this task will be a procedural checklist which will be followed in the actual testing of the network proof-of-performance.

Table 10 3 0-2. WBS Definitions (Continued)

XXX-10-01-05-02 NETWORK TRACKING VALIDATION PROCEDURES

This task includes those systems analyses, mission engineering, flight control and flight support efforts required to develop a checkout procedure which will exercise the tracking capabilities of the support network from the flight control and flight support consoles in the Mission Control Center The output of this task will be a procedural checklist which will be followed in the actual testing of the network proof-of-performance

320-10-01-05-03 SPACE TUG NETWORK DATA HANDLING REQUIREMENTS

This task includes all efforts required to produce a document levying specific data handling, processing, and special requirements on the supporting network This includes both updata and downdata processing

XXX-10-01-05-03 IUS NETWORK DATA HANDLING REQUIREMENTS

This task includes all efforts required to produce a document levying specific data handling, processing, and special requirements on the supporting network This includes both updata and downdata processing

320-10-01-05-04 TUG NETWORK DATA VALIDATION PROCEDURES

This task includes all efforts required to establish proof-of-performance criteria for the acceptance test of Tug-peculiar ground software.

XXX-10-01-05-04 IUS NETWORK DATA VALIDATION PROCEDURES

This task includes all efforts required to establish proof-of-performance criteria for the acceptance test of IUS-peculiar ground software.

320-10-02 OPERATIONAL PREPARATIONS

This element includes efforts to establish the interface with the data acquisition network, to design the basic layout of flight control consoles and flight support consoles, and to establish the display format, engineering units and special processing requirements for data display to flight control and flight support personnel

320-10-02-01 DESIGN NETWORK INTERFACE

This task includes the engineering effort necessary to establish the interface with the data acquisition network. It specifically includes telemetry decommutation and special processing, command processing, television, and tracking format and processing requirements. The output of this task will be the operational requirements for a network interface system design which will include suggested hardware items

320-10-02-02 CONSOLE ORGANIZATION

This task includes all efforts necessary to establish the requirements for location of console display and control devices to the satisfaction of the console operating personnel

320-10-02-03 TUG DISPLAY FORMAT DESIGN

This task includes all efforts required to establish the organizational, display format and engineering units for flight control and flight support personnel digital TV presentation This task also includes all efforts directed toward the definition of the special processing requirements, remote site and control center logical operations, limit sensing, event light triggering, etc

XXX-10-02-03 IUS DISPLAY FORMAT DESIGN

This task includes all efforts required to establish the organization, display format and engineering units for flight control and flight support personnel digital TV presentation This task also includes all efforts directed toward the definition of the special processing requirements, remote site and control center logical operations, limit sensing, event light triggering, etc

320-10-03 MISSION READINESS TESTING

This element includes all efforts required to set-up and conduct pre-mission proof-of-performance tests on the flow of data into the control center from the ground site(s) of the data acquisition network

XXX-10-03-01 NETWORK TRACKING VALIDATION TESTS

This task includes all efforts required to set up and conduct specific pre-mission tests of the tracking capabilities and tracking accuracies of the support network This will involve the generation of tapes to simulate over-flying vehicles and ground receiving tracking stations, the distribution and execution of procedures previously prepared and the evaluation of test results

320-10-03-02 SPACE TUG NETWORK VALIDATION TESTS

This task includes all efforts required to conduct tests of the network handling of Space Tug peculiar software, including the providing of vehicle simulation tapes to remote sites of the ground data acquisition network, providing the procedures to remote operations, and providing personnel to conduct these tests.

XXX-10-03-02 IUS NETWORK VALIDATION TESTS

This task includes all efforts required to conduct tests of the network handling of IUS-peculiar software, including the providing of vehicle simulation tapes to remote sites of the ground data acquisition network, providing the procedures to remote operators, and providing personnel to conduct these tests

320-10-04 CONDUCT SPACE TUG MISSION OPERATIONS

This task includes all efforts necessary to provide control and support to the Space Tug vehicle in prelaunch, orbital operations, placement, retrieval

and landing phases. This task requires the total attention of the flight control team, the flight support team, and other personnel This task is the culmination of all prior efforts.

XXX-10-04 CONDUCT IUS MISSION OPERATIONS

This task includes all efforts necessary to provide control and support to the IUS vehicle in prelaunch, orbital operations and placement mission phases. This task requires the total attention of the flight control team, the flight support team, and other personnel This task is the culmination of all prior efforts

320-15 SOFTWARE

This element summarizes all tasks and services required to analyze, develop, verify and implement Tug and IUS software It includes design, processing and implementation of software (computer languages, computer programs, program verification, debugging, etc.) for ground and airborne subsystems.

320-15-01 FLIGHT SOFTWARE

This element consists of task and services required to analyze, design, develop, simulate, verify and maintain software for use onboard the IUS or Tug to support IUS and Tug requirements

320-15-01-01 PLAN FLIGHT SOFTWARE DEVELOPMENT

This task includes all efforts required to establish a schedule for development of the flight software, establish design concept validation procedures, establish the necessity for, and required characteristics of, hybrid and interpretive simulators, establishing a plan for the integration of the IUS and Space Tug flight software development to minimize cost, and establishing controls and feedback to insure customer requirements on the IUS and Space Tug flight software are fulfilled

320-15-01-02 BASELINE FLIGHT PROGRAM DEVELOPMENT

This element includes the creation of an Equation Defining Document (EDD), programming and verification of four basic flight programs for the IUS and four basic flight programs for the Space Tug

320-15-01-02-01 EQUATION DEFINING DOCUMENT - SPACE TUG FLIGHT PROGRAM

This task includes basic conceptual work on the requirements for flight software, customer support and flight software definition, definitions of equations pertaining to vehicle dynamics, design of algorithm techniques and the associated simulation equipments, the generation of a program requirements document known as the Equation Defining Document (EDD), control of requirements, performance of software implementation studies, analysis of sample calculations, definition of flight control functional interfaces, definition of hardware interfaces, and miscellaneous preliminary analysis.

XXX-15-01-02-01 EQUATION DEFINING DOCUMENT - IUS FLIGHT PROGRAM

This task includes basic conceptual work on the requirements for flight software, customer support and flight software definition, definitions of equations pertaining to vehicle dynamics, a design of algorithm techniques and the associated simulation equipments, the generation of a program requirements document known as the Equation Defining Document (EDD), control of requirements, performance of software implementation studies, analysis of sample calculations, definition of flight control functional interfaces, definition of hardware interfaces, and miscellaneous preliminary analysis

320-15-01-02-02 PROGRAM TUG FLIGHT SOFTWARE

This task includes all efforts required to develop preflight and flight software to satisfy baseline requirements Included are performance of overall software system design based on execution rates, input/output requirements, and response time restrictions, design and develop documentation, participate in design reviews, perform systematic integration testing of software, update software as a result of change activity, participate in configuration control, and perform program delivery generation and validation

XXX-15-01-02-02 PROGRAM IUS FLIGHT SOFTWARE

This task includes all efforts required to develop preflight and flight software to satisfy baseline requirements Included are performance of overall software system design based on execution rates, input/output requirements, and response time restrictions; design and develop executive and application program modules, generate detailed software design documentation, participate in design reviews, perform systematic integration testings of software, update software as a result of change activity, participate in configuration control, and perform program delivery generation and validation

320-15-01-02-03 SPACE TUG FLIGHT PROGRAM VERIFICATION

The objective of program verification is to insure, thru systematic testing by a independent functional area, that the flight software satisfies all requirements levied on it by the Equation Defining Document To accomplish this objective, the following activities are performed analysis of software reqirements, generation of a detailed testing plan, performance of systematic tests, analysis of software listings, comparison of flight software derived results with independently generated results, analysis of hardware/software compatability, reverification of all changes made to the software and generation of documented test results.

XXX-15-01-02-03 IUS FLIGHT PROGRAM VERIFICATION

The objective of program verification is to insure, thru systematic testing by an independent functional area, that the flight software satisfies all requirements levied on it by the Equation Defi ing Document To accomplish this objective, the following activities are performed analysis of software requirements, generation of a detailed testing plan, performance of systematic tests, analysis of software listings, comparison of flight software derived

results with independently generated results, analysis of hardware/software compatibility, reverification of all changes made to the software and generation of documented test results.

320-15-01-03 MISSION SPECIFIC PROGRAM MODIFICATION

This element includes all efforts required to modify the baseline flight programs to perform specific IUS or Space Tug missions This includes the EDD, programming and verification of mission specific "application modules".

320-15-01-03-01 TUG MISSION SPECIFIC EQUATION DEFINING DOCUMENT (EDD)

This task includes all efforts required to modify the definition of the baseline Space Tug flight program to incorporate mission specific peculiarities. This task is iterative and must be repeated prior to each flight

XXX-15-01-03-01 IUS MISSION SPECIFIC EQUATION DEFINING DOCUMENT (EDD)

This task includes all efforts required to modify the definition of the baseline IUS flight program to incorporate mission specific pecularities This task is iterative and must be repeated prior to each flight

320-15-01-03-02 TUG MISSION SPECIFIC PROGRAMMING

This task develops the "application module" which incorporates the specific deviations from the baseline program required by the subject Space Tug mission This task is iterative and must be repeated prior to each flight.

XXX-15-01-03-02 IUS MISSION SPECIFIC PROGRAMMING

This task develops the "application Module" which incorporates specific deviations from the baseline program required by the subject IUS mission. This task is iterative and must be repeated prior to each flight

320-15-01-03-03 TUG MISSION PROGRAM VERIFICATION

This task includes efforts necessary to analyze flight program implementation of the Equation Defining Document for this "application module" The task includes generation of a detailed testing plan to insure that all requirements are satisfied, the performance of systematic tests, and generation of a test results document

XXX-15-01-03-03 IUS MISSION PROGRAM VERIFICATION

This task includes efforts necessary to analyze flight program implementation of the Equation Defining Document for this "application module" The task includes generation of a detailed testing plan to insure that all requirements are satisfied, the performance of systematic tests, and generation of a test results document

320-15-02 GROUND SOFTWARE

This element consists of tasks and services required to analyze, design, develop, simulate, verify and maintain software used in the IUS/Space Tug Mission control center

320-15-02-01 PLAN GROUND SOFTWARE DEVELOPMENT

This task includes all efforts necessary to establish a plan for the development of IUS and Space Tug ground software Included will be the advisability of transforming software modules from existing ground control systems, establishment of the basic data processing techniques, planning the use of existing ground system simulators, and establishing ground program organization and source strings, and establishing a maximum transfer capability between IUS and Space Tug ground support software

320-15-02-02 EQUATION DEFINITION

This element consists of all efforts in equation definition and algorithm development for Space Tug and IUS ground programs

320-15-02-02-01 EQUATION DEFINING DOCUMENT - EXECUTIVE/TRACKING/ PLANNING SOFTWARE

This task includes those efforts from the definition and analysis to the development of the equations and algorithms to be utilized in the Space Tug and IUS ground programs It is limited to those equations and algorithms which will not change during transition from IUS operations to Space Tug operations, with the exception of the IUS-peculiar tracking requirements, which will be phased out when the IUS becomes non-operational

320-15-02-02-02 TUG DOWN DATA/UP DATA AND DOCKING GROUND SOFTWARE

This task includes all efforts required to create an Equation Defining Document (EDD) for those ground software modules which are specifically oriented to the Space Tug The output of this task is an Equation Defining Document against which the ground Tug-peculiar software will be programmed

XXX-15-02-02-02 IUS DOWN DATA/UP DATA AND SIMULATION GROUND SOFTWARE

This task includes all efforts required to create an Equation Defining Document (EDD) for those ground software modules which are specifically oriented to the IUS. The output of this task is an Equation Defining Document against which the ground IUS-peculiar software will be programmed

320-15-02-03 PROGRAMMING

This element includes the coding of all equations and algorithms specified for the IUS and Space Tug Ground programs

320-15-02-03-01 PROGRAM GROUND TRACKING, PLANNING AND EXECUTIVE ROUTINES

This task depends on the generation of an adequate Equation Defining Document at a prior time, and includes the programming of all fundamental routines

320-15-02-03-02 PROGRAM SPACE TUG DOWN DATA/UP DATA AND SIMULATION SYSTEM

This task includes all efforts required to design an overall software system based on execution rates, input/output requirements, and response restrictions, design and develop Tug specific program modules, generating a detailed software design document, participation in design reviews, perform software integration testing, participate in change reviews and update software, provide configuration control and perform program generation, delivery and validation

XXX-15-02-03-02 PROGRAM IUS DOWN DATA, UP DATA AND SIMULATION SYSTEM

This task includes all efforts required to design an overall software system based on execution rates, input/output requirements, and response restrictions, design and develop IUS specific program modules, generating a detailed software design document, participation in design reviews, perform software integration testing, participate in change reviews and update software, provide configuration control and perform program generation, delivery and validation

320-15-02-04 PROGRAM VERIFICATION

This task includes all activities required to insure, through systematic testing by an independent functional area, that the ground software developed meets the intent of the Equation Defining Documents

320-15-02-04-01 VERIFY EXECUTIVE TRACKING AND PLANNING SOFTWARE

This task verifies that the intent of the Equation Defining Document has been implemented in the developed programs by testing the coded program under critical operational situations and includes the development of any special tools or simulators necessary in the accomplishment of this task.

320-15-02-04-02 VERIFY TUG DOWN DATA/UP DATA AND SIMULATION PROGRAMMING

This task includes all activities involved to insure, thru systematic testing by an independent functional area, that the Tug peculiar ground software satisfies all requirements levied upon it by the Equation Defining Document This includes analysis of software requirements to insure accuracy, adequacy, and completeness, generation of a detailed testing plan, performance of systematic tests utilizing interpretive simulators, analysis of software listings, analysis of hardware/software compatibility and validation of all changes made to the basic software package

XXX-15-02-04-02 VERIFY IUS DOWN DATA/UP DATA AND SIMULATION PROGRAMMING

This task includes all activities involved to insure, thru systematic testing by an independent functional area, that the IUS-peculiar ground software satifies all requirements levied upon it by the Equation Defining Document. This includes analysis of software requirements to insure accuracy, adequacy, and completeness, generation of a detailed testing plan, performance of systematic tests utilizing interpretive simulators, analysis of software listings, analysis of hardware/software compatibility and validation of all changes made to the basic software package

320-15-02-05 MISSION SPECIFIC SIMULATION

This element includes all efforts in equation definition, programming and verification required to incorporate specific mission profiles and contingency cases into the basic IUS or Space Tug simulation.

320-15-02-05-01 PROGRAM TUG MISSION SIMULATION

This task includes all efforts required to modify the baseline Tug simulator to incorporate mission specific profiles and contingency cases This task accepts as inputs the output from the Space Tug mission planning and optimization task, and the Space Tug abort planning task, as well as outputs from Space Tug basic simulation design This task is iterative and must be repeated for each flight This task is, in a sense, a mission specific simulation application module.

XXX-15-02-05-01 PROGRAM IUS MISSION SIMULATION

This task includes all efforts required to modify the baseline IUS simulator to incorporate mission specific profiles and contingency cases This task accepts as inputs the output from the IUS mission planning and optimization task, and the IUS abort planning task, as well as outputs from IUS basic simulation design This task is iterative and must be repeated for each flight This task is in a sense a mission simulation application module

320-15-02-06 GROUND SOFTWARE MAINTENANCE

This element includes efforts required to maintain the ground software in operable condition and to incorporate modification and enhancements to the ground programs This is a level of effort task

320-15-03 COMPUTER SELECTION SUPPORT

This element includes all analytical tasks involved in the selection of the optimum operational data system for the IUS/Space Tug Control Center

320-15-03-01 ESTIMATE GROUND SOFTWARE SIZE

This task analyzes the Equation Defining Document for ground software and establishes a lower boundary upon the data system memory size and central processor unit speed requirements For maximum cost-effectiveness this task should be completed prior to the selection of an operational data system

10.4 IUS/SPACE TUG PHASEOVER CONSTRAINTS

This section evaluates the current planning of IUS and Space Tug traffic, then schedules the earliest and latest times to effect transition on an element by element basis.

10 4 1 Observations From the Space Transportation System Traffic Model

The space transportation system traffic model is imprecisely defined at this time. The best available information indicates that the first NASA IUS flight will take place in April, 1981.

The information developed in this section is based upon the following basic assumptions

1. NASA and DoD will not share a common facility or operational interface.
2. The IUS will be Expendable at level B autonomy
3. The IUS will have a digital command system similar to the Space Tug command system.
4. The Space Tug configuration will be at Level II autonomy.
5. Communications equipment will have similar external characteristics for both the IUS and Space Tug.
6. Telemetry and command format will have maximum similarity for IUS and Space Tug configurations.

The Tug Fleet and Ground Operations Schedules and Controls Study, Second Performance Review Report, (Martin Marietta Corporation report MCR-74-487, December 10 -12, 1974) offers three options for expendable IUS utilization. Option one presumes immediate phasing between IUS and Space Tug with no transition. The last IUS flight to occur in 1983, and the first Tug flight to occur in early 1984. The second model presumes a transition through the year 1984 during which time both IUS and Space Tug missions will be flown The third option takes advantage of the expendable nature of the IUS to substitute for Space Tug carrier vehicles on missions where the carrier vehicle must be expended.

Preliminary planning thus indicates, in the later two cases, that the ability to simultaneously control the Space Tug and the IUS is a program requirement. To accommodate any overlap, it is obvious that maximum commonality of ground equipment must be a program objective. The composite IUS/SPACE TUG Work Breakdown Structure and Dictionary presented in Section 10.3 of this report has presumed maximum commonality of equipment performing similar functions. The telemetry and command systems are more vulnerable to impact by vehicle individual peculiarities, and will thus be

carried as separate line items in the development plan It will be presumed that there will be no additional personnel requirements resulting from the overlap of IUS and Space Tug missions

10.4 2 Common Elements Development Plan

Table 10 4 2-1 lists the elements common to both the IUS and Space Tug programs These elements fall into the following general areas

1. Program planning and schedule analysis

2 Console hardware design requirements and selection

3 Network interface design requirements and equipment selection

4. Operational data system

5. Physical Plant

6 Ground software in the areas of operating system (the executive) and mission planning

Some of the tasks listed in Table 10 4.2-1 are constrained by the completion of tasks which are unique to either the IUS and Space Tug program. Section 10-6 will present an integrated program development plan in which the constraining relationships are discussed

10 4.3 Modifiable Elements Development and Phasing Plan

Table 10.4 3-1 presents the elements modifiable for IUS to Space Tug utilization Those elements are the maintenance schedule, the network interface design, the display format design, and the console position guidelines

The maintenance schedule will include all periodic contracted and schedulable maintenance activities throughout the IUS Space Tug era. The maintenance plan is dependent upon a number of factors, one of these factors is the kind and type of equipment to be maintained. The Space Tug will bring additional hardware online to support television monitored rendezvous and docking acitivites. The addition of Space Tug peculiar equipment will force a modification of the baseline maintenance schedule planning

Similarly, the Space Tug program will bring additional equipment items into the network interface, particularly television related items. Additionally, it is expected that there will be some deviation in telemetry format and command uplink requirements and format as the Space Tug control system is brought on line The initial selection of equipment should be sufficiently flexible to encompass both IUS and Space Tug network interface constraints, however, some modification of the network interface should be expected during the transition period when Space Tug is becoming the dominant program.

Table 10 4 2 I. Elements Common to IUS and Space Tug

MASTER LAUNCH SCHEDULE ANALYSIS
CONTRACT SOFTWARE DEVELOPMENT
PLAN FACILITY UTILIZATION
PLAN FLIGHT SOFTWARE DEVELOPMENT
PLAN GROUND SOFTWARE DEVELOPMENT
MISSION PHASE MANNING REQUIREMENTS
COMPUTER UTILIZATION PLAN
MAINTENANCE SCHEDULE
HIRE CONTROL AND SUPPORT STAFF
CONSOLE ORGANIZATION
DESIGN NETWORK INTERFACE SYSTEM
ESTIMATE GROUND SOFTWARE SIZE
SELECT OPERATIONAL DATA SYSTEM
INSTALL OPERATIONAL DATA SYSTEM
SIZE FACILITY/DESIGN PHYSICAL PLANT
CONSTRUCT PHYSICAL PLANT
INSTALL OPERATIONAL CONSOLES/HARDWARE
EDD-EXECUTIVE/TRACKING/PLANNING
COMMON GND SW VALID TEST REQUIREMENTS
PROGRAM GROUND TK/PLAN/EX SOFTWARE
VERIFY EXECUTIVE/TK/PLAN SOFTWARE

Table 10.4 3-1 Elements Modifiable from IUS to Space Tug

MAINTENANCE SCHEDULE
DESIGN NETWORK INTERFACE
DISPLAY FORMAT DESIGN
CONSOLE POSITION GUIDELINES

Display format design is a function of the vehicle systems configuration, parameters downlinked, and command uplink requirements (except in the area of flight dynamics). In the flight dynamics area the disparity of trajectory expectations between the IUS expendable missions and the Space Tug recoverable missions will require an update and modification of the flight dynamics related console displays

Console positions guidelines define the operational relationships and organizational hierarchy which implements the control philosophy for a particular program This task will be executed once for the IUS program and then modified for Space Tug implementation based upon experience gained during the IUS program. It has been observed that, historically, duties and responsibilities of a particular console position are reallocated as the program matures The integrated IUS/SPACE TUG program allows an opportunity for planning the modification of console position guidelines at a convenient time in the transition between programs.

10 4 4 IUS Elements Development Plan

Table 10 4 4-1 presents the elements unique to the IUS program The elements fall into eight broad categories, mission design, flight program design, development and verification, IUS peculiar training and training criteria, network IUS data handling requirements, ground programs in the IUS specific areas of tracking, down data, up data, and simulation interagency relationships, as related to other NASA centers and the DoD, IUS mission specific elements, and IUS post-mission reports

The IUS peculiar elements and the common elements must be completed before the first IUS launch (with the exception of IUS post-mission reports). The overall development plan presented in Section 10-6 will illustrate that, to meet an April 1981 launch of an Interim Upper Stage, the development of the common and IUS peculiar operational elements must start no later than January, 1977

10 4 5 Space Tug Unique Elements Development Plan

Table 10 4 5-1 present the Space Tug unique operational elements. These fall into the general categories of mission design, flight program design, development and verification, Space Tug training and training criteria, Space Tug peculiar network data handling requirements, ground programs in the areas of down data processing, up data processing, docking support, Space Tug simulation, interagency relationships, Space Tug mission specific elements, and Space Tug mission reports.

The transition plan presented in Section 10.6 shows that in order to meet a fourth quarter 1983 launch with the Space Tug it is necessary to begin the Space Tug peculiar operational element development no later than February 1982. This is presuming that the tasks which are common to the IUS and Space Tug have been completed in support of the IUS program It should be noted that IUS operations will be continuing during the time that the Space Tug peculiar program development tasks are being performed.

Table 10 4 4 1 Elements Unique to the IUS Program

IUS MISSION CHARACTERIZATION
EDD-IUS FLIGHT PROGRAM
IUS DOWNDATA UPDATA SIMULATION
IUS GND SW VALID TEST REQUIREMENTS
OBTAIN IUS SYSTEM CHARACTERISTICS
DETERMINE IUS FAILURE MODES
IUS DISPLAY FORMAT DESIGN
IUS MISSION FAILURE EFFECTS
DESIGN IUS MISSION SIMULATION
ANALYZE IUS COMPONENT CHARACTERISTICS
IUS TRAINING REQ/CRIT/SIMSKED
PREPARE IUS SYSTEMS HANDBOOK
PUBLISH/UPDATE IUS HANDBOOK
DEVELOP IUS TRAINING MATERIAL
IUS CLASSROOM TRAINING
IUS NETWORK DATA HANDLING REQUIREMENTS
IUS NETWORK DATA VALID PROCEDURES
IUS NETWORK DATA VALID TESTS
PROGRAM IUS DNDATA/UPDATA/SIMULATION
PROGRAM IUS FLIGHT SOFTWARE
VERIFY IUS DNDATA/UPDATA/SIM PROGRAMS
CONSOLE POSITION GUIDELINES
IUS MISSION PLANNING AND OPTIMIZATION
DEVELOP IUS PROCEDURES AND RULES
IUS ABORT PLANNING
IUS INTERAGENCY COORDINATION
IUS FLT PROGRAM VERIFICATION
PREPARE IUS INTERAGENCY DOCUMENTS
PROGRAM IUS MISSION SIMULATION
IUS MISSION SPEC EDD
IUS MISSION SPEC PROGRAM
IUS MISSION PROGRAM VERIFICATION
IUS MISSION SIMULATION TRAINING
CONDUCT IUS MISSION OPERATIONS
IUS POST MISSION REPORTS
DEFINE IUS OPERATOR CERT/CRITERIA
DEFINE NETWORK TRACKING REQUIREMENTS
NETWORK TRACKING VALID PROCEDURES
NETWORK TRACKING VALID TESTS

Table 10 4 5-1 Elements Unique to the Space Tug Program

OBTAIN SPACE TUG SYSTEM CHARACTERISTICS
TUG MISSION CHARACTERIZATION
EDD-TUG FLIGHT PROGRAM
TUG DOWNDATA UPDATA DOCKING SIMULATION
TUG GND SW VALID TEST REQUIREMENTS
DETERMINE TUG FAILURE MODES
TUG DISPLAY FORMAT DESIGN
TUG MISSION FAILURE EFFECTS
DESIGN TUG MISSION SIMULATION
ANALYZE TUG COMPONENT CHARACTERISTICS
TUG TRAINING REQ/CRIT/SIMSKED
PREPARE TUG SYSTEMS HANDBOOK
PUBLISH/UPDATE TUG SYSTEMS HANDBOOK
DEVELOP TUG TRAINING MATERIAL
TUG CLASSROOM TRAINING
TUG NETWORK DATA HANDLING REQUIREMENTS
TUG NETWORK DATA VALID PROCEDURES
TUG NETWORK VALID TESTS
PROGRAM TUG DNDATA/UPDATA/SIMULATION
PROGRAM TUG FLIGHT SOFTWARE
VERIFY TUG DNDATA/UPDATA/SIM PROGRAMS
TUG CONSOLE POSITION GUIDELINES
TUG MISSION PLANNING AND OPTIMIZATION
DEVELOP TUG PROCEDURES AND RULES
TUG ABORT PLANNING
TUG INTERAGENCY COORDINATION
TUG FLT PROGRAM VERIFICATION
PREPARE TUG INTERAGENCY DOCUMENT
PROGRAM TUG MISSION SIMULATION
TUG MISSION SPEC EDD
TUG MISSION SPECIFIC PROGRAM
TUG MISSION PROGRAM VERIFICATION
TUG MISSION SIMULATION TRAINING
CONDUCT TUG MISSION OPERATIONS
TUG POST MISSION REPORTS
DEFINE TUG OPERATOR CERT/CRITERIA

10 5 UTILIZATION OF COMMON OPERATIONAL ELEMENTS

The most cost-effective approach to the overall space transportation system problem in the upper stage area is to maximize the utilization of operational support elements which are common between the IUS and the Space Tug program. The key to maximizing this utilization is in the detail, adequacy and flexibility of the initial planning effort.

There are four basic plans which must be generated in detail and adhered to in execution. Those are Facility Utilization Plan, Flight Software Development Plan, Ground Software Development Plan, and the Computer Utilization Plan.

The Facility Utilization Plan should consider those programs which are co-resident with the IUS and/or the Space Tug program within the same physical plant.

The Flight Software Development and Ground Software Development Plans should be constructed to include all flight and ground software for both IUS and Space Tug programs. A well thought out plan would include the utilization of modules developed for mission planning in the ground software as tools for the evaluation of the flight software

The Computer Utilization Plan will establish a pre-emption hierarchy for utilization of the computer. The computer should be dedicated to mission control, mission planning, and flight software development, with the remaining time being devoted to such functions as batch processing, payroll, etc.

Early, detailed and adequate planning is required in order to maximize the utilization of the common support elements.

The physical plant should be initially designed to fit the maximum requirements of all programs resident within the physical plant. In the case of the IUS and Space Tug, the Space Tug will require more consoles and more personnel than the Expendable IUS. Therefore, the initial layout of console communications groups, display devices, and etc., should be sized to the Space Tug requirements. The IUS will operate on a sub-set of the Space Tug system. The consoles should be designed to be compatible with both IUS and Space Tug requirements. The initial layout of console equipment should be established early and would ideally be the result of requirements specified by both IUS and Space Tug operational personnel. The consoles will be installed in a fixed relationship which will not be varied in the transition phase. That is, a console devoted to avionics display and control in the IUS program will be dedicated to avionics in the Space Tug program as well. Organizational hierarchy, which to an extent influences the orientiation and selection of console locations, will be be constant between the IUS and Space Tug programs. The consoles will be designed so that the display formats are flexible. The background information, engineering unit and parameter selections should be software variable. In that way, deviation in parameter names, scales and relative position on display will be functions of the ground software programs, and not hardware. The presumption is that it is always easier to change software than to change hardware.

In order to develop a Transition Plan, we first constructed a PERT chart, and then performed operations on that PERT flow until a comprehensive development plan was established for both the IUS and the Space Tug programs Figure 10 5 0-1 presents the PERT chart for the composite program.

The PERT chart was generated by the IBM mini-PERT program which was designed for terminal usage, and therefore is not in the form most frequently seen Briefly, the chart consists of a series of event designators displayed across the top of the chart, and strings of activties which span the space between event designators. An event designator may be thought of as being equivalent to a "bubble" on the more frequently seen PERT chart. The significance of the event designator is that it represents a point in the activity flow of a program which must be reached prior to beginning of activities "planned ground software development" before the activity generate ground software equation defining document may begin.

There are two times associated with each event, an early date and a late date. These dates are considered to be either starting dates or finishing dates depending upon whether you are considering the activities which begin at the event, or activities which end at the event The early and late dates of the event correspond with the early and late dates of the associated activities For example, for event 26, the earliest that activities subsequent to event 26 can begin is April 11, 1977, which is the earliest that all constraints can be met. And September 18, 1978, is the latest that predecessor activities can begin without impacting the overall schedule

The activity is bounded on each end by an event, and the time space between the event is determined by the effort that must be applied during the activity. An activity is time consuming and resource consuming.

Progression of activities is from left to right across chart with vertical extensions to pick up parallel activity paths.

There exists a path which constrains the earliest date the project can be finished as a function of the established date that the project must start This path is called the "critical path", and all activities in the program may be fit within the constraints of the beginning and ending of the critical path. In generating the PERT chart, the critical paths for the IUS and Space Tug program were created by postulating a first mission for the IUS in April, 1981, and a first mission for the Space Tug in November, 1983. These postulates establish the latest possible start time for (IUS and common) elements in the first quarter of 1977. The initial launch of Space Tug in November, 1983, requires the beginning of the Space Tug peculiar efforts in February, 1982, assuming that all of the common development has been completed in order to support the IUS program.

A bar chart of the overall program is presented in Figure 10.5 0-2. The bar chart is segregated into calendar quarters spanning the time from first quarter 1977 through fourth quarter 1983

Table 10.5 0-1 Man-Hour Loading of DDT&E Tasks

CNT	PRED	SUCC	START	FINISH	DUR	DESC	SA	PM	Y	FP	FC	FS	GP	A
1	START	25	6/12/78	7/24/78	6 0	MASTER LAUNCH SCHEDULE ANAL	240.0	240.0	480 0					
2	START	3	1/03/77	2/28/77	8 0	CONTRACT SOFTWARE DEVELOPME		960 0						320.0
3	25	6	3/05/79	4/02/79	4.0	PLAN FACILITY UTILIZATION		320 0						80 0
4	3	18	10/30/78	12/11/78	6 0	PLAN FLIGHT SOFTWARE DEVELO	1540.0			386.0				
5	3	7	2/28/77	4/11/77	6.0	PLAN GROUND SOFTWARE DEVELO	960.0						240.0	
6	26	27	9/18/78	10/16/78	4.0	MISSION PHASE MANNING REQUI		160 0	320.0					
7	26	8	12/25/78	2/19/79	8.0	COMPUTER UTILIZATION PLAN	320.0	320.0	320.0			120.0		320.0
8	26	12	11/12/79	12/24/79	6.0	MAINTENANCE SCHEDULE		120.0				120.0		120 0
9	27	2	10/16/78	11/27/78	6 0	HIRE CONTROL ANS SUPPORT ST		60.0	60.0					240.0
10	2	6	3/05/79	4/02/79	4.0	CONSOLE ORGANIZATION					160.0	80.0		
11	4	6	1/08/79	4/02/79	12.0	DESIGN NETWORK INTERFACE SY					960.0	960.0		
12	9	8	1/22/79	2/19/79	4.0	ESTIMATE GROUND SOFTWARE SI	1600.0		320.0					
13	8	6	2/19/79	4/02/79	6.0	SELECT OPERATIONAL DATA SYS	120.0	80.0				240.0		240.0
14	12	19	12/24/79	5/12/80	20.0	INSTALL OPERATIONAL DATA SY	120.0					653 0		120.0
15	6	10	4/02/79	6/25/79	12 0	SIZE FACILITY/DESIGN PHYSIC		200 0	160.0			120.0		40 0
16	10	12	6/25/79	12/24/79	26.0	CONSTRUCT PHYSICAL PLANT		40.0						160.0
17	12	19	12/24/79	5/12/80	20.0	INSTALL OPERATIONAL CONSOLE					800.0	4000.0		
18	7	9	4/11/77	9/11/78	74.0	EDD-EXECUTIVE/TRACKING/PLAN	57858.0		5786.0		5786.0	5786 0		
19	7	19	3/03/80	5/12/80	10.0	COMMON GND SW V'LID TEST RE	4691 0		782 0		782 0	1564.0		
20	6	22	10/27/80	11/24/80	4.0	DEFINE NETWORK TRACKING REQ	160.0	40 0	320.0		160.0	320.0		40.0

SA = SYSTEM ANALYSIS
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FC = FLIGHT CONTROLLERS
FS = FLIGHT SUPPORT PERSONNEL
GP = GROUND PROGRAMMERS
A = ADMINISTRATION

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Table 10.5 0-1 Man-Hour Loading of DDT&E Tasks (Continued)

CNT	PRED	SUCC	START	FINISH	DUR	DESC	SA	PM	Y	FP	FC	FS	GP	A
21	22	23	11/24/80	1/19/81	8.0	NETWORK TRACKING VALID PROC	320 0				1280 0	640.0		
22	23	IIOC	1/19/81	3/16/81	8.0	NETWORK TRACKING VALID TEST		120.0			320.0	320.0		
23	9	N	9/11/78	9/10/79	52.0	PROGRAM GROUND TK/PLAN/EX S	4106 0		2033.0				265832.0	
24	N	19	9/10/79	5/12/80	35.0	VERIFY EXECUTIVE/TK/PLAN SO	27065 0		2737 0				13682 0	
25	2	4	11/27/78	1/08/79	6.0	OBTAIN SPACE TUG SYSTEM CHA		240.0			720 0	360 0		
26	25	26	7/24/78	9/18/78	8 0	TUG MISSION CHARACTERIZATIO			720.0		240.0	120.0		
27	I1	T1	9/19/80	3/19/82	78 0	EDD-TUG FLIGHT PROGRAM	16948 0		5007.0		5007.0			
28	7	9	4/11/77	9/11/78	74 0	EDD-TUG DOWNDATA/UPDATA/DOC	50977.0		5098.0		5098 0	5098.0		
29	7	19S	8/06/82	10/15/82	10.0	TUG GND SW VALID TEST REQUI	4133.0		689 0		689 0	1378 0		
30	52I	41T	10/15/82	12/10/82	8.0	DETERMINE TUG FAILURE MODES			640 0		6400.0			
31	4	6	2/05/79	4/02/79	8 0	TUG DISPLAY FORMAT DESIGN			320.0		6400.0	3600.0		
32	41T	5T	12/10/82	2/04/83	8.0	TUG MISSION FAILURE EFFECTS	640.0		640.0		6400 0			
33	5T	15T	2/04/83	4/29/83	12.0	DESIGN TUG MISSION SIMULATI	480.0		960 0			960 0		
34	5T	51T	3/18/83	4/29/83	6.0	ANALYZE TUG COMPONENT CHARA			480.0		4800.0	240 0		
35	5T	13T	4/29/83	6/24/83	8.0	TUG TRAINING REQ/CRIT/SIMSK		640 0			320 0	320 0		320 0
36	51T	52T	4/29/83	6/24/83	8.0	PREPARE TUG SYSTEMS HANDBOO			160 0		640 0			320.0
37	52T	16T	6/24/83	9/16/83	12.0	PUBLISH/UPDATE TUG SYSTEMS			480 0		480.0			480.0
38	13T	14T	6/24/83	8/19/83	8.0	DEVELOP TUG TRAINING MATERI		80.0	320.0		1600 0	1600.0		320 0
39	14T	16T	8/19/83	9/16/83	4.0	TUG CLASSROOM TRAINING			160 0		3200 0	3680.0		
40	IIOC	22T	6/10/83	7/08/83	4 0	TUG NETWORK DATA HANDLING R	160.0	40 0	320.0		320 0	320.0		40 0

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Table 10 5 0-1 Man-Hour Loading of DDT&E Tasks (Continued)

CNT	PRED	SUCC	START	FINISH	DUR	DESC	SA	PM	Y	FP	FC	FS	GP	A
41	22T	23T	7/08/83	9/02/83	8 0	TUG NETWORK DATA VALID PROC	320.0				1280.0	640.0		
42	23T	TIOC	9/02/83	10/28/83	8 0	TUG NETWORK VALID TESTS		120.0			320.0	320.0		
43	N	T	6/12/81	2/12/82	35 0	PROGRAM TUG DNDATA/UPDATA/D	2411 0		1171.0				155004.0	
44	T1	T2	3/19/82	10/08/82	29.0	PROGRAM TUG FLIGHT SOFTWARE	3852.0			70618.0	2054.0			
45	T	19S-	2/12/82	10/15/82	35.0	VERIFY TUG DNDATA/UPDATA/DO	24112.0		2411.0					
46	27	5T	11/12/82	2/04/83	12.0	TUG CONSOLE POSITION GUIDEL		480.0	960.0		1440.0	1440.0		
47	19S	111T	12/24/82	2/04/83	6.0	TUG MISSION PLANNING AND OP	1920.0		480.0		480.0			
48	19S	5T	10/15/82	2/04/83	16.0	DEVELOP TUG PROCEDURES AND	320.0				3200.0	3200.0		
49	111T	15T	2/04/83	4/29/83	12.0	TUG ABORT PLANNING	960.0		240.0		240.0			
50	21T	TIOC	9/02/83	10/28/83	8.0	TUG INTERAGENCY COORDINATIO		640.0			320.0	320.0		
51	T2	15T	10/08/82	4/29/83	29.0	TUG FLT PROGRAM VERIFICATIO	89877.0		8988.0					
52	15T	21T	7/08/83	9/02/83	8 0	PREPARE TUG INTERAGENCY DOC		320 0	1280.0		640 0	640.0		640.0
53	15T	16T	6/24/83	9/16/83	12.0	PROGRAM TUG MISSION SIMULAT	240.0		240.0				2400.0	
54	15T	151T	4/29/83	5/27/83	4 0	TUG MISSION SPEC EDD	2568 0		257 0		257.0	257.0		
55	151T	152T	5/27/83	7/22/83	8 0	TUG MISSION SPECIFIC PROGRA	1028 0			5136.0	514.0			
56	152T	16T	7/22/83	9/16/83	8.0	TUG MISSION PROGRAM VERIFIC	5136.0		514 0					
57	16T	TIOC	9/16/83	10/28/83	6.0	TUG MISSION SIMULATION TRAI	240 0	240 0	240 0		4800 0	5520.0		
58	TIOC	24T	10/28/83	11/04/83	1.0	CONDUCT TUG MISSION OPERATI	40 0	120.0	40 0		1200 0	1380.0		
59	24T	TCYCL	11/04/83	12/30/83	8.0	TUG POST MISSION REPORTS	320.0	320.0	3200.0		3200.0	3200.0	-	- -
60	26	5T	1/07/83	2/04/83	4 0	DEFINE TUG OPERATOR CERT/CR		320 0	800 0		160.0	160.0		

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Table 10 5 0-1 Man Hour Loading of DDT&E Tasks (Continued)

CNT	PRED	SUCC	START	FINISH	DUR	DESC	SA	PM	Y	FP	FC	FS	GP	A
61	25	26	7/24/78	9/18/78	8.0	IUS MISSION CHARACTERIZATIO			720 0		240.0	120 0		
62	18	I1	12/11/78	12/10/79	52 0	EDD+IUS FLIGHT PROGRAM	9375.0		2679 0		2679 0			
63	7	9	9/1?/77	9/11/78	52.0	EDD-IUS DOWNDATA/UPDATA/SIM	35189.0		3519 0		3519 0	3519 0		
64	7	19	3/24/80	5/12/80	7.0	IUS GND SW VALID TEST REQUI	3284.0		547 0		547.0	1094 0		
65	2	4	11/27/78	1/08/79	6.0	OBTAIN IUS SYSTEM CHARACTER		240.0			720 0			
66	4	41I	3/03/80	4/28/80	8.0	DETERMINE IUS FAILURE MODES			640 0		6400.0			
67	4	6	2/05/79	4/02/79	8.0	IUS DISPLAY FORMAT DESIGN			320.0		6400 0	3600 0		
68	41I	5I	4/28/80	6/23/80	8 0	IUS MISSION FAILURE EFFECTS	640 0		640.0		6400.0			
69	5I	15I	6/23/80	9/15/80	12 0	DESIGN IUS MISSION SIMULATI	480.0		960 0			960 0		
70	5I	51I	8/04/80	9/15/80	6.0	ANALYZE IUS COMPONENT CHARA			480 0		4800 0	240.0		
71	5I	13I	9/15/80	11/10/80	8.0	IUS TRAINING REQ/CRIT/SIMSK		640 0				320.0		320.0
72	51I	52I	9/15/80	11/10/80	8.0	PREPARE IUS SYSTEMS HANDBOO			160 0		640 0			320 0
73	52I	16I	11/10/80	2/02/81	12.0	PUBLISH/UPDATE IUS HANDBOOK			480 0		480.0			480.0
74	13I	14I	11/10/80	1/05/81	8 0	DEVELOP IUS TRAINING MATERI		80.0	320.0		1600.0	1600.0		320.0
75	14I	16I	1/05/81	2/02/81	4.0	IUS CLASSROOM TRAINING			160 0		3200.0	3680.0		
76	6	22I	10/27/80	11/24/80	4.0	IUS NETWORK DATA HANDLING R	160 0	40 0	320 0		320 0	320.0		40.0
77	22I	23I	11/24/80	1/19/81	8.0	IUS NETWORK DATA VALID PROC	320 0				1280 0	640 0		
78	23I	II0C	1/19/81	3/16/81	8.0	IUS NETWORK DATA VALID TEST		120 0			320 0	320.0		
79	9	I	4/23/79	12/24/79	35.0	PROGRAM IUS DNDATA/UPDATA/S	2739.0		1329 0				117280.0	
80	I1	I2	12/10/79	4/28/80	20.0	PROGRAM IUS FLIGHT SOFTWARE	2143 0			38839 0	1125.0			

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GP = GROUND PROGRAMMERS
A = ADMINISTRATION

Table 10.5.0-1 Man-Hour Loading of DDT&E Tasks (Continued)

CNT	PRED	SUCC	START	FINISH	DUR	DESC	SA	PM	Y	FP	FC	FS	GP	A
81	I	19	12/24/79	5/12/80	20.0	VERIFY IUS DNDATA/UPDATA/SI	14660.0		1564.0					
82	27	5I	3/31/80	6/23/80	12 0	CONSOLE POSITION GUIDELINES		480.0	960 0		1440.0	1440.0		
83	19	111I	5/12/80	6/23/80	6.0	IUS MISSION PLANNING AND OP	1920.0		480.0		480.0			
84	19	15I	5/26/80	9/15/80	16.0	DEVELOP IUS PROCEDURES AND	[illegible]20.0				3200.0	3200.0		
85	111I	15I	6/23/80	9/15/80	12.0	IUS ABORT PLANNING	960.0		240.0		240.0			
86	21I	IIOC	1/19/81	3/16/81	8.0	IUS INTERAGENCY COORDINATIO		640.0			320.0	320.0		
87	I2	15I	4/28/80	9/15/80	20.0	IUS FLT PROGRAM VERIFICATIO	42857.0		4286.0					
88	15I	21I	11/24/80	1/19/81	8.0	PREPARE IUS INTERAGENCY DOC		320.0	1280.0		640 0	640.0		640.0
89	15I	16I	11/10/80	2/02/81	12.0	PROGRAM IUS MISSION SIMULAT	240.0		240.0				2400.0	
90	15I	151I	9/15/80	10/13/80	4.0	IUS MISSION SPEC EDD	2143.0		214.0		214.0	214.0		
91	151I	152I	10/13/80	12/08/80	8.0	IUS MISSION SPEC PROGRAM	857.0			4286.0	429 0			
92	152I	16I	12/08/80	2/02/81	8.0	IUS MISSION PROGRAM VERIFIC	4286.0		429.0					
93	16I	IIOC	2/02/81	3/16/81	6.0	IUS MISSION SIMULATION TRAI	240.0	240.0	240.0		4800.0	5520.0		
94	IIOC	24I	3/16/81	3/23/81	1.0	CONDUCT IUS MISSION OPERATI	40 0	120.0	40.0		1200.0	1380.0		
95	24I	ICYCL	3/23/81	5/18/81	8.0	IUS POST MISSION REPORTS	320.0	320.0	3200.0		3200 0	3200.0		
96	26	5I	5/26/80	6/23/80	4.0	DEFINE IUS OPERATOR CERT/CR		320.0	800 0		160.0	160 0		
				TOTALS			429255 0	9780.0	77380 0	119265.0	29660.0	82163.0	556838 0	5920.0

SA = SYSTEM ANALYSIS
PM = PROGRAM MANAGEMENT
Y = MISSION ENGINEERS
FP = FLIGHT PROGRAMMERS
FC = FLIGHT CONTROLLERS
FS = FLIGHT SUPPORT PERSONNEL
GP = GROUND PROGRAMMERS
A = ADMINISTRATION

The information in Table 10 5 0-1 is operated upon by the mini-PERT program which spreads the number of manhours estimated across the time allocated for the accomplishment of a task. The program selects either the early (*E*) acitivity bars or the late (*L*) activity bars. It was elected to spread the manhours across the late (*L*) activities because it is felt this represents the most realistic probability for the availability of funds and manpower to accomplish the IUS and Space Tug task. It is an easy option to select the early (*E*) spread should NASA so desire.

Table 10 5 0-2 presents the results of the manpower spread across the PERT network from first quarter 1977 through the fourth quarter 1983 This chart defines the type of skill required by the month in which that skill is required and by the number of men necessary in any given month to accomplish all of the tasks which must be worked during that month For example, in May, 1977, twenty Systems Analysts are required, two Mission Engineers are required, two Flight Controllers are required, and two Flight Support personnel are required, making a total of twenty-six loaded against the IUS/SPACE TUG program during that month. Monthly totals and totals by skill are provided along the margins of the yearly printouts

The manpower distribution is surprisingly flat across the program considering that the information is a first iteration analysis The next step is then to select the optimum time from the bar chart (Figure 10 5 0-2) during which the optional activities may be scheduled in order to level the total manpower requirements within a given skill. It should be emphasized that the loading of manpower is against the DDT&E schedule and does not include the loading for recurring manpower efforts in support of the IUS program These can be added in at a later time to create the overall picture.

Table 10 5 0-2 DDT&E Manpower Requirements

IUS/TUG MISSION OPERATIONS
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MANPOWER 1977

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSTS	0 0	0 2	4 0	15 4	20 0	20 0	20 0	20 0	25 9	28 7	28 7	28 7	211 6
PROGRAM MANAGEMENT	3 0	2 9	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	5 9
MISSION ENGINEERS	0 0	0 0	0 0	1 4	2 0	2 0	2 0	2 0	2 6	2 9	2 9	2 9	20 7
FLIGHT PROGRAMMERS													
FLIGHT CONTROLLERS	0 0	0 0	0 0	1 4	2 0	2 0	2 0	2 0	2 6	2 9	2 9	2 9	20 7
FLIGHT SUPPORT PERSO	0 0	0 0	0 0	1 4	2 0	2 0	2 0	2 0	2 6	2 9	2 9	2 9	20 7
GROUND PROGRAMMERS	0 0	0 1	1 0	0 3	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 4
ADMINISTRATORS	1 0	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 0
MONTHLY TOTALS	4 0	4 2	5 0	19 9	26 0	26 0	26 0	26 0	33 7	37 4	37 4	37 4	283 0

MANPOWER 1978

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSTS	28 7	28 7	28 7	28 7	28 7	29 3	29 4	28 7	8 9	1 4	5 0	4 8	251 0
PROGRAM MANAGEMENT	0 0	0 0	0 0	0 0	0 0	0 7	0 7	0 0	0 5	0 6	0 6	2 2	5 3
MISSION ENGINEERS	2 9	2 9	2 9	2 9	2 9	4 2	5 6	7 4	4 5	1 5	0 7	1 4	39 8
FLIGHT PROGRAMMERS	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 1	1 0	0 3	1 4
FLIGHT CONTROLLERS	2 9	2 9	2 9	2 9	2 9	2 9	3 3	4 4	1 6	0 0	1 1	6 7	34 5
FLIGHT SUPPORT PERSO	2 9	2 9	2 9	2 9	2 9	2 9	3 1	3 6	1 2	0 0	0 3	1 6	27 2
GROUND PROGRAMMERS	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	46 7	65 4	65 4	65 4	242 9
ADMINISTRATORS	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 5	0 8	0 2	1 5
MONTHLY TOTALS	37 4	37 4	37 4	37 4	37 4	40 0	42 1	44 1	63 4	69 5	74 9	82 6	603 6

MANPOWER 1979

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSTS	8 8	11 2	4 9	4 7	5 4	5 4	5 4	5 4	12 1	14 4	14 4	15 8	107 9
PROGRAM MANAGEMENT	1 4	0 7	2 2	0 4	0 4	0 3	0 0	0 0	0 0	0 0	0 4	0 4	6 2
MISSION ENGINEERS	3 2	5 1	3 5	1 9	2 3	2 2	1 9	1 9	2 3	2 4	2 4	1 9	31 0
FLIGHT PROGRAMMERS	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	27 6	27 6
FLIGHT CONTROLLERS	3 8	39 0	43 9	1 0	1 0	1 0	1 0	1 0	1 0	1 0	1 0	1 3	96 0
FLIGHT SUPPORT PERSO	2 3	22 9	26 0	0 3	0 3	0 2	0 0	0 0	0 0	0 0	0 3	2 0	54 3
GROUND PROGRAMMERS	65 4	65 4	65 4	77 6	108 2	108 2	108 2	108 2	63 0	47 9	47 9	35 6	901 0
ADMINISTRATORS	1 0	1 0	1 5	0 1	0 1	0 1	0 2	0 2	0 2	0 2	0 5	0 5	5 6
MONTHLY TOTALS	85 9	145 3	147 4	86 0	117 7	117 4	116 7	116 7	78 6	65 9	66 9	85 1	1229 6

MANPOWER 1980

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSTS	21 5	21 5	29 2	39 0	57 6	48 5	43 5	43 5	26 5	8 6	7 8	14 1	361 3
PROGRAM MANAGEMENT	0 0	0 0	0 0	1 0	1 5	2 1	0 0	0 0	1 1	2 1	1 3	1 3	10 4
MISSION ENGINEERS	2 0	2 0	5 4	8 5	11 8	12 6	6 5	8 4	5 0	2 7	7 0	8 3	80 2
FLIGHT PROGRAMMERS	36 3	36 3	36 3	31 3	0 0	0 0	0 0	0 0	0 0	6 5	10 0	2 2	158 9
FLIGHT CONTROLLERS	2 1	2 1	23 5	26 9	26 7	23 7	5 5	24 5	13 6	4 7	11 8	17 2	182 3
FLIGHT SUPPORT PERSO	5 8	5 8	8 5	12 8	7 5	8 4	7 0	8 0	4 7	2 2	8 5	11 0	90 2
GROUND PROGRAMMERS	5 0	5 0	5 0	5 0	1 6	0 0	0 0	0 0	0 0	0 0	3 8	5 0	30 4
ADMINISTRATORS	0 2	0 2	0 2	0 2	0 0	0 0	0 0	0 0	1 1	2 1	2 9	4 0	10 9
MONTHLY TOTALS	72 9	72 9	108 1	124 7	106 7	95 3	62 5	84 4	52 0	28 9	53 1	63 1	924 6

Table 10 5 0-2 DDT&E Manpower Requirements (Continued)

IUS/TUG MISSION OPERATIONS
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MANPOWER 1981

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSTS	15 0	4 4	4 4	4 4	3 9	4 0	4 4	4 4	4 4	4 4	4 4	4 4	62 5
PROGRAM MANAGEMENT	1 8	3 8	2 7	1 0	0 5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	9 8
MISSION ENGINEERS	6 7	2 0	4 9	11 0	6 2	1 3	1 5	1 5	1 5	1 5	1 5	1 5	41 1
FLIGHT PROGRAMMERS													
FLIGHT CONTROLLERS	27 5	24 0	21 5	11 0	6 2	1 0	1 0	1 0	1 0	1 0	1 0	1 0	97 2
FLIGHT SUPPORT PERSO	26 0	26 0	22 8	10 0	5 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	90 0
GROUND PROGRAMMERS	5 0	0 0	0 0	0 0	0 0	38 0	64 3	64 3	64 3	64 3	64 3	64 3	428 8
ADMINISTRATORS	2 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 2
MONTHLY TOTALS	84 2	60 2	56 3	37 4	22 0	44 3	71 2	71 2	71 2	71 2	71 2	71 2	731 6

MANPOWER 1982

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSTS	4 4	9 3	12 9	12 1	12 1	12 1	12 1	17 0	18 1	45 2	48 8	50 5	254 6
PROGRAM MANAGEMENT	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 6	1 0	2 6
MISSION ENGINEERS	1 5	1 8	1 6	1 0	1 0	1 0	1 0	1 8	2 0	5 7	8 0	9 3	35 7
FLIGHT PROGRAMMERS	0 0	0 0	14 8	37 9	37 9	37 9	37 9	37 9	37 9	9 0	0 0	0 0	251 2
FLIGHT CONTROLLERS	1 0	1 0	1 0	1 1	1 1	1 1	1 1	1 9	2 1	13 8	26 8	28 5	80 5
FLIGHT SUPPORT PERSO	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 6	2 0	3 6	6 8	8 0	22 3
GROUND PROGRAMMERS	64 3	28 9	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	93 2
ADMINISTRATORS												0 0	0 0
MONTHLY TOTALS	71 2	41 0	30 3	52 1	52 1	52 1	52 1	60 2	62 1	77 3	91 0	97 3	740 1

MANPOWER 1983

CATEGORY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
SYSTEMS ANALYSIS	56 8	54 2	53 3	53 3	10 0	2 9	5 5	11 5	5 8	1 0	1 3	1 0	256 6
PROGRAM MANAGEMENT	2 5	0 8	0 0	0 0	2 0	0 3	1 1	1 2	2 9	3 4	1 8	1 0	17 0
MISSION ENGINEERS	12 5	9 0	10 3	11 3	1 5	4 0	6 3	7 8	2 3	1 0	10 3	10 0	103 3
FLIGHT PROGRAMMERS	0 0	0 0	0 0	0 0	0 0	10 0	7 5	0 0	0 0	0 0	0 0	0 0	17 5
FLIGHT CONTROLLERS	10 7	19 7	30 0	40 5	4 0	6 3	11 8	20 8	22 5	22 0	17 5	10 0	215 8
FLIGHT SUPPORT PERSO	8 7	3 8	3 0	3 0	2 0	3 5	8 5	19 3	25 0	24 0	18 6	10 0	129 4
GROUND PROGRAMMERS	0 0	0 0	0 0	0 0	0 0	1 3	5 0	5 0	2 5	0 0	0 0	0 0	13 8
ADMINISTRATORS	0 0	0 0	0 0	0 0	0 0	1 7	3 6	3 8	5	0 0	0 0	0 0	9 6
MONTHLY TOTALS	91 2	87 5	96 6	108 1	19 5	30 0	49 3	69 4	61 5	51 4	49 5	32 0	763 0

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10 6 COMPOSITE IUS/SPACE TUG SUMMARY COST DATA

Figure 10 6.0-1 presents the composite IUS/Space Tug program expenditures for a 180 month program Based on a time 0 date of January 1977, the IUS will become operational in April 1981, and Space Tug will become operational in November 1983 The IUS Program is considered to be over at the IOC of the Space Tug Program

The composite IUS/Space Tug Program expenditures exceed $100 million over the program life The curves are derived by adding together the IUS DDT&E expenditures prior to April 1981, the Space Tug DDT&E expenditures prior to November 1983, and the IUS recurring cost expenditures between April 1981 and November 1983, and the Space Tug recurring cost expenditures from November 1983 until the end of the program

Figure 10 6 0-2 presents the IUS Program and Space Tug DDT&E rate of expenditure This is an amplification of the first 86 months of the program In Figure 10 6 0-2 the IUS Program absorbs the hardware, data system, ground software, and physical plant expenditures The actual journaling of those expenditures is a Government decision, since the equipment will belong to the Space Tug Program after the IUS has become non-operational

The average monthly expenditure over the 86 month composite IUS Program and Space Tug DDT&E is approximately $663,000. This includes the major hardware expenditure in the 41st month of $8 04 million

Figure 10 6 0-3 presents the manpower requirements in equivalent men-per-month based on the composite IUS/Space Tug program schedule This curve represents manpower expended on DDT&E tasks only It does not include any estimate of manpower required to conduct IUS operations over the period from April 1981 through November 1983 In any event, the total man-load over that period should not increase greater than 60 additional men per month, and upon entering the Space Tug operational period at the end of 1983 the total manning will drop to approximately 64

The man-loading curve presents information based upon assumptions that the schedule is loaded such that each task is performed as late as possible without resulting in an overall slip of schedule This results in a net right shift of expenditure, which delays funding to the maximum extent. It should be noted that other combinations of tasks and other schedules are possible which can smooth or reduce man-load peaks. Volume IV of the Orbital Operations and Mission Support Study final report presents a schedule bar chart which identifies the available rescheduling options to the NASA

COMPOSITE IUS/SPACE TUG PROGRAM EXPENDITURES, ORBITAL OPERATIONS AND MISSION SUPPORT

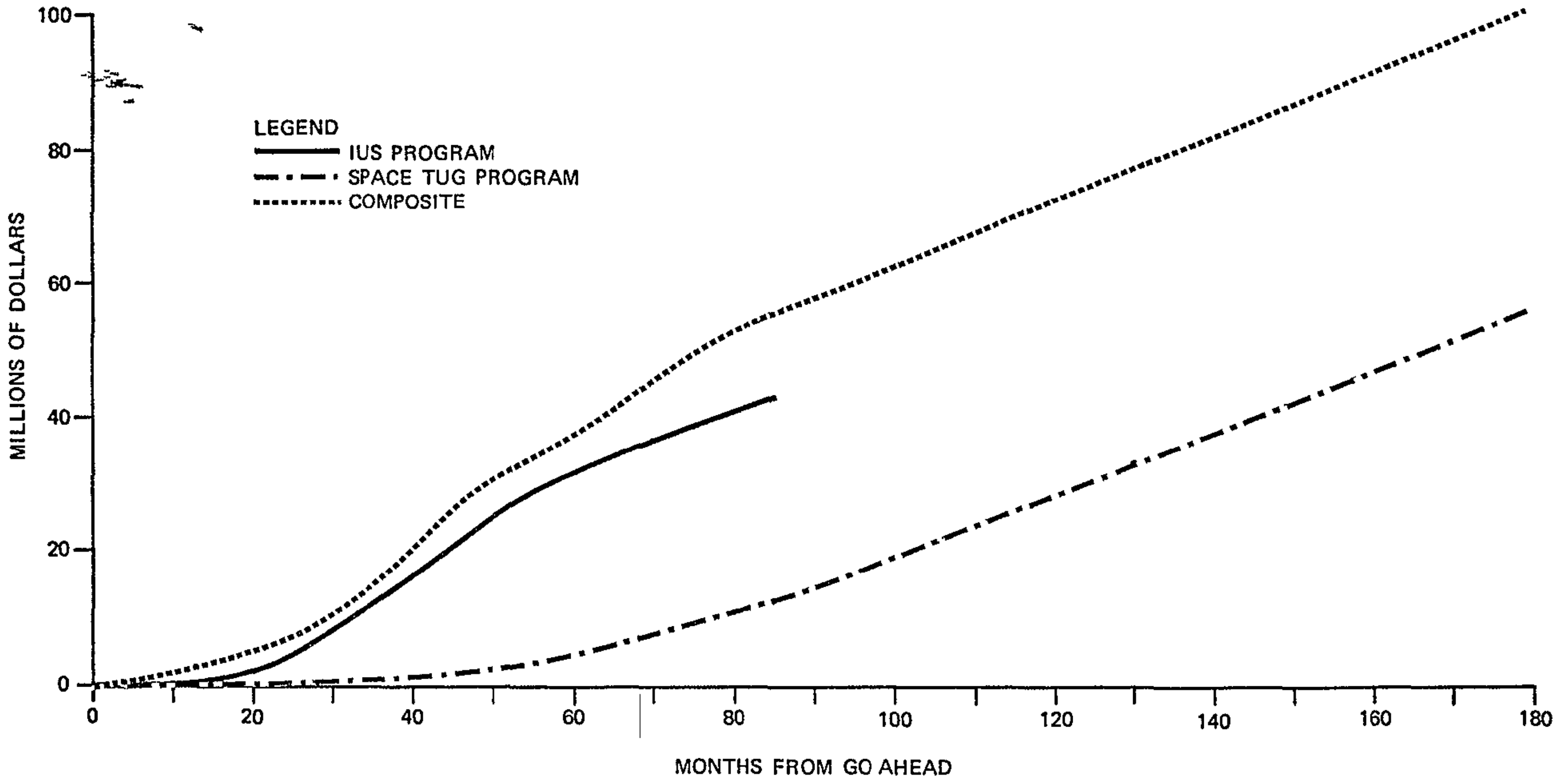

Figure 10 6 0-1 Composite IUS/Space Tug Program Expenditures (OO/MS)

IUS PROGRAM AND SPACE TUG DDT&E RATE OF EXPENDITURE, ORBITAL OPERATIONS AND MISSION SUPPORT

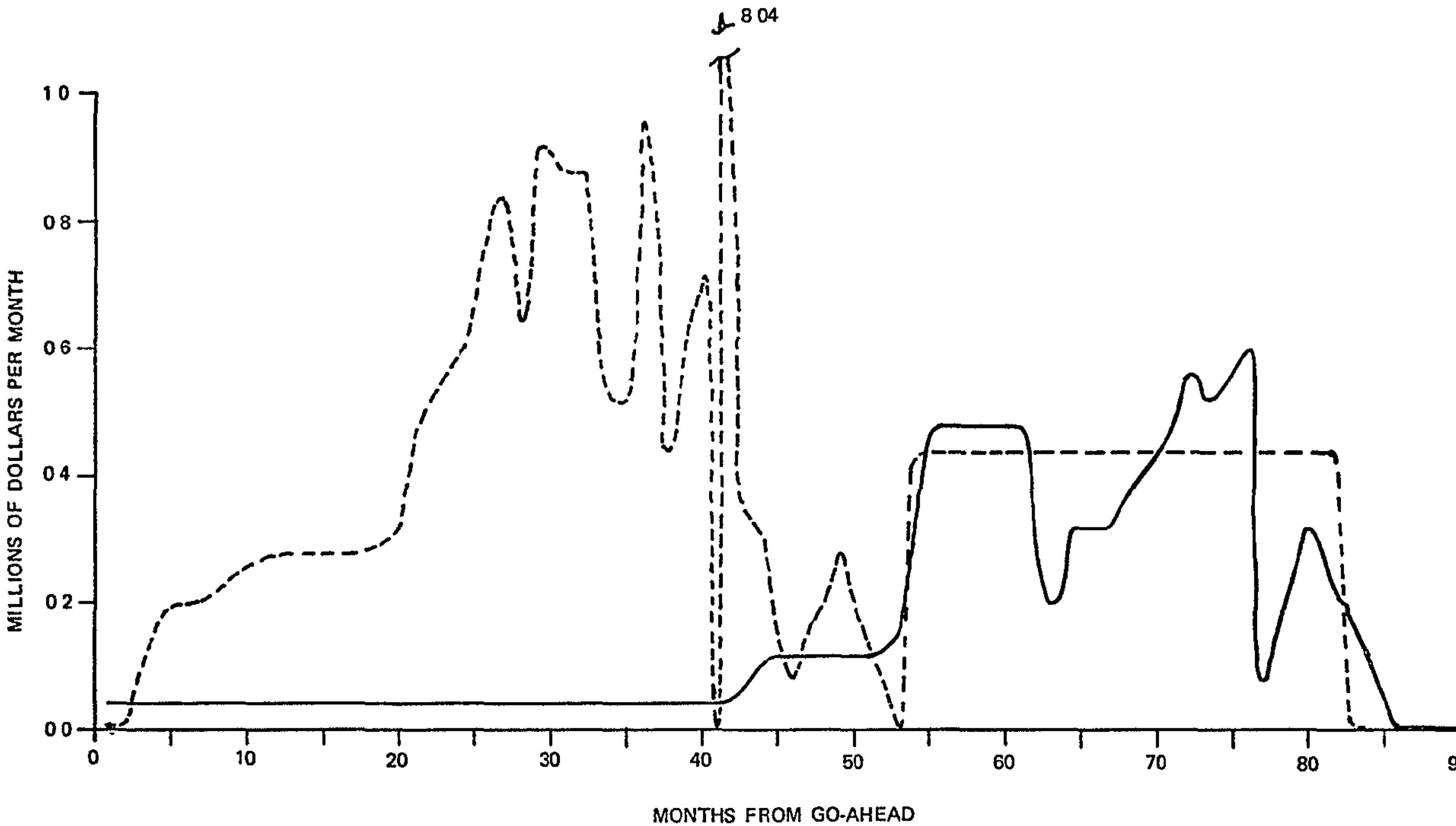

Figure 10 6 0-2 IUS Program and Space Tug DDT&E Rate of Expenditure (OO/MS)

DDT&E MANLOADING CURVE, ORBITAL OPERATIONS AND MISSION SUPPORT

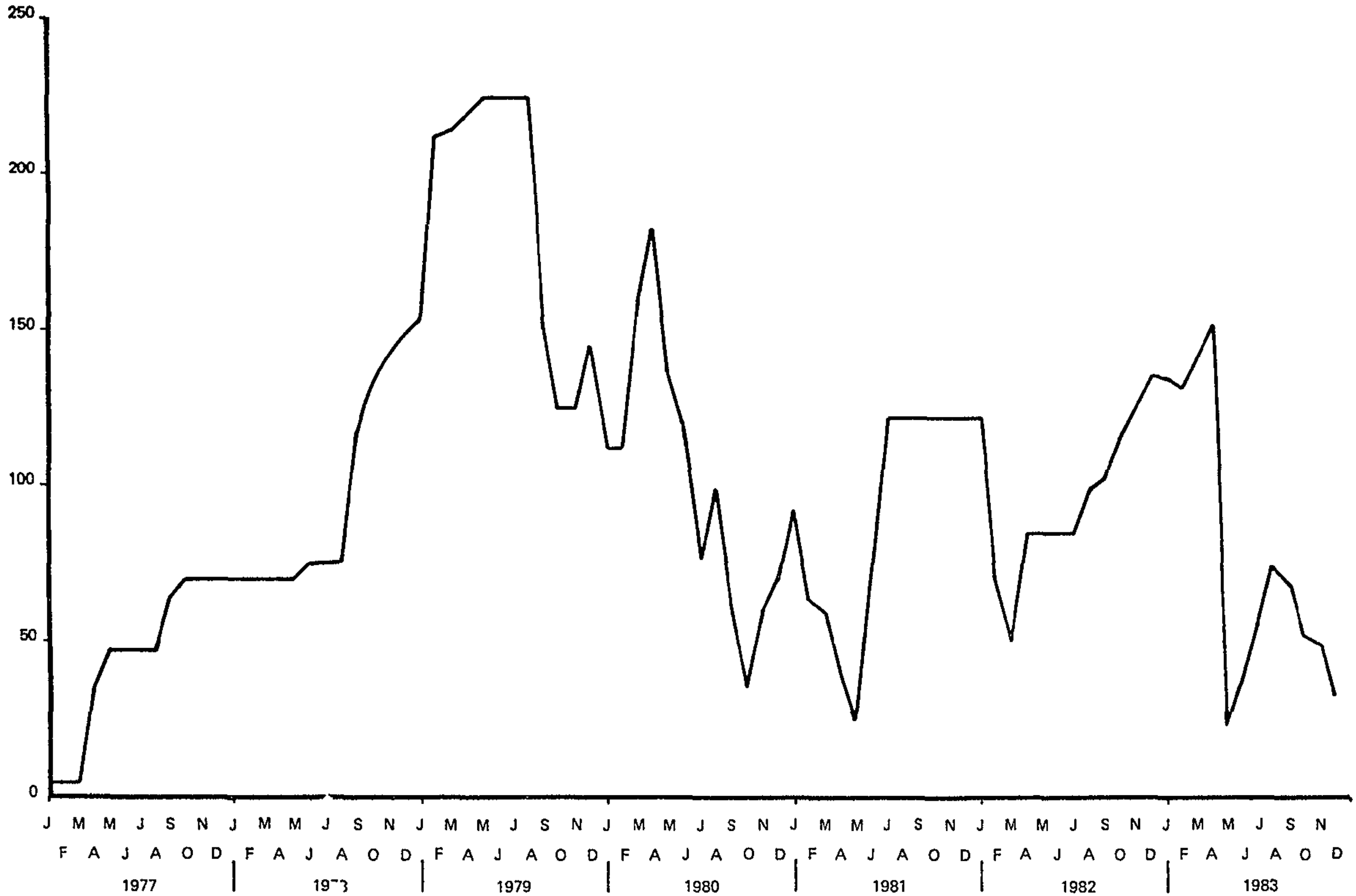

Figure 10 6 0-3 DDT&E Equivalent Men-Per-Month Curve (OO/MS)

Peak loading occurs in May 1979 This is 225 6 equivalent personnel. The minimum loading occurs in May 1982 at 23 1 personnel This does not include IUS operational personnel If the IUS operational personnel are included, then the minimum number of personnel applied to the program becomes 63 1 in May 1981

Table 10 6 0-1 presents a cost summary of the composite IUS/Space Tug DDT&E expenditures This summary was derived by adding togehter the composite program costs, then identifying definable lost of cost, such as

Table 10 6 0-1. Cost Summary Composite DDT&E Costs

TOTAL DEVELOPMENT COST	
ELEMENT	DOLLARS
PHYSICAL PLANT	418620
TOC SOFTWARE DEVELOPMENT	18983200
DATA SYSTEM	7010008
OPERATIONS STAFF EQUIPMENT	1052400
IUS SOFTWARE DEVELOPMENT	2729197
TUG SOFTWARE DEVELOPMENT	5058689
SERVICE ACTIVITIES	5533614
TOTAL	40785728
TOTAL IUS DDT&E	27483428
TOTAL TUG DDT&E	27899738
TOTAL COMPOSITE DDT&E	55383136
	(-)40785728
NET SAVINGS	14597438

physical plant, data system, operations staff equipment, IUS software development, Space Tug software development and ground operation center software development When these definable tasks were subtracted from the composite program costs, a residual of $5 53 million was obtained This residual is composed principally of manpower expenditures for planning and coordination efforts On Table 10.6 0-1 that charge has been identified as service activities

It is of interest to examine net savings resulting from combining the IUS and Space Tug DDT&E expenditures Table 10 6 0-1 demonstrates that $14 56 million are saved by combining IUS and Space Tug orbital operations and mission support functions The major portion of those savings is the ground computer software development

Figure 10 6 0-4 presents the IUS program cumulative expenditures Bear in mind when examining this curve, that the major hardware purchases are incurred during the IUS DDT&E period and thus bias the IUS curve upward

Figure 10 6 0-5 presents the IUS program rate of expenditure curve This curve was shown earlier as the IUS contribution to the IUS program and Space Tug DDT&E rated expenditure shown in Figure 10 6 0-2

Figure 10 6 0-6 presents the Space Tug DDT&E rate of expenditure curve. This curve was shown earlier as the Space Tug DDT&E contribution to Figure 10 6 0-2 The Space Tug DDT&E period may be said to begin in January 1977 along with the IUS program, during which Space Tug peculiar operational problems are being worked in conjunction with the similar operational problems of the IUS The major portion of Space Tug effort is intentionally delayed until the IUS becomes operational in order to avoid excessive overlap of the DDT&E phases

Figure 10 6.0-7 presents the Space Tug program cumulative DDT&E expenditures It should be noted that Space Tug program costs presented on this curve presume the IUS program has borne the expenses of major hardware expenditures and common element costs

10 7 RECURRING COSTS - OPERATIONS

Figure 10 7 0-1 presents a schedule of recurring tasks which will be followed for each flight Man-loading on that schedule is for the first flight operation It is anticipated that the sequence of operations will remain pretty much the same as the program matures, but that the man-loading of each task will be significantly reduced as the program matures

Figure 10 7 0-2 presents a typical mission operations cycle, specifically man-loaded for the initial launch operation On the basis of Figure 10 7 0-2, the first launch should cost NASA $1 887 million The cost of the first launch operation is included in the DDT&E expense presented in Section 10 6 it is included in this section for orientation purposes only. The actual cost per flight should be computed by dividing the recurring expenditures over the entire program by the total number of IUS and Space Tug launches. This gives an average cost per flight estimate of $375,800 per flight

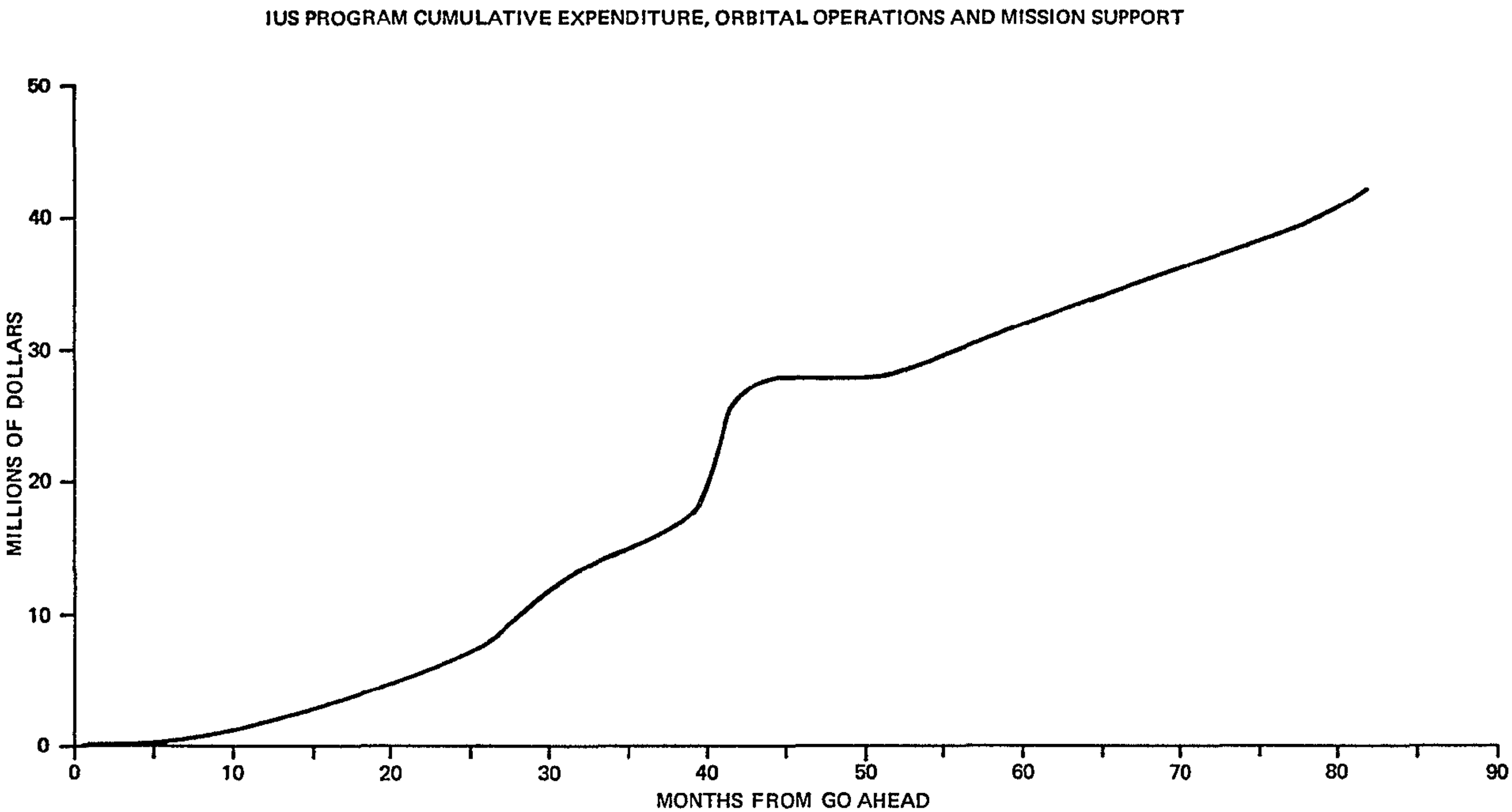

Figure 10 6.0-4 IUS Program Cumulative Expenditures (OO/MS)

IUS PROGRAM RATE OF EXPENDITURE, ORBITAL OPERATIONS AND MISSION SUPPORT

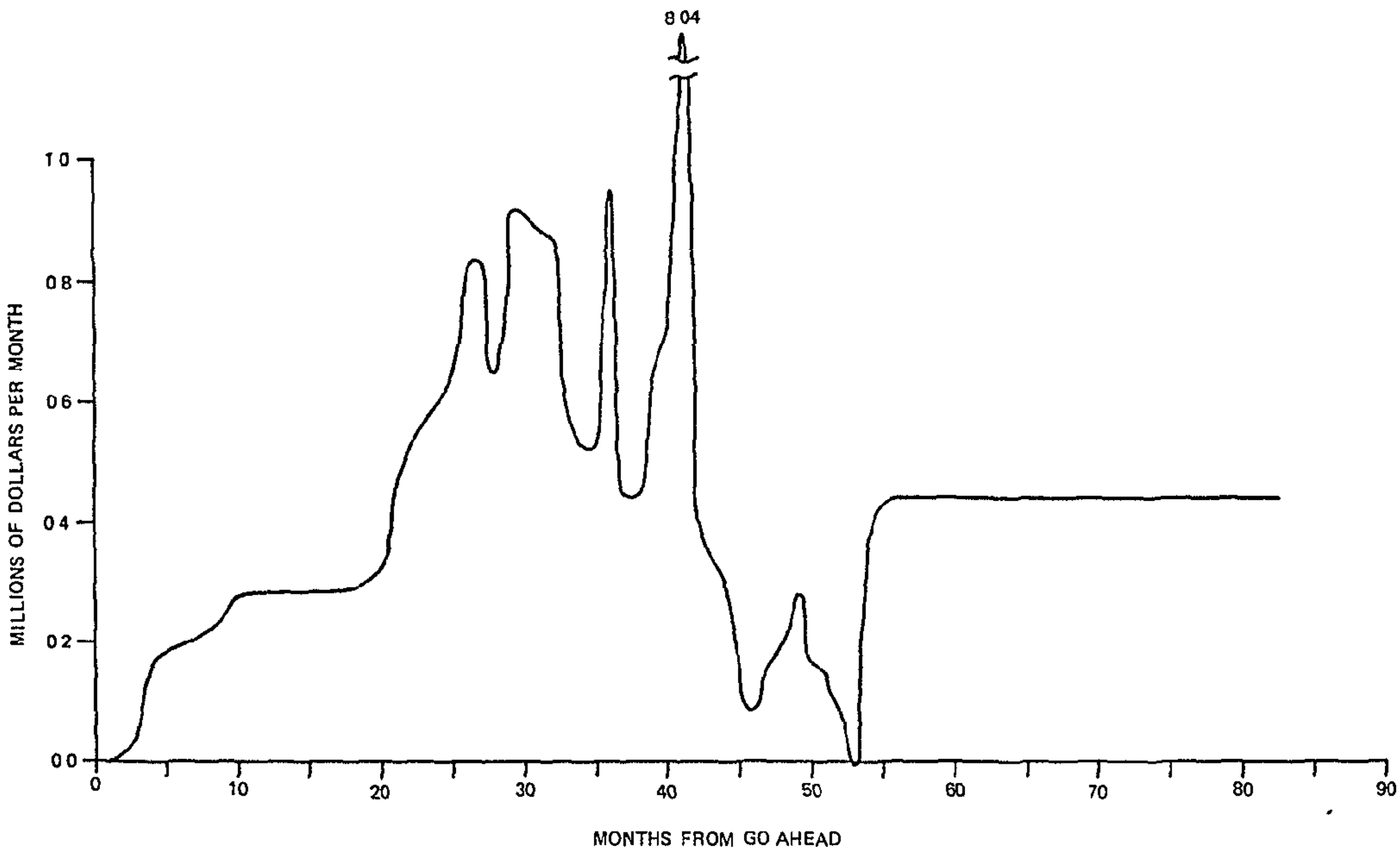

Figure 10 6 0-5 IUS Program Rate of Expenditure Curve (OO/MS)

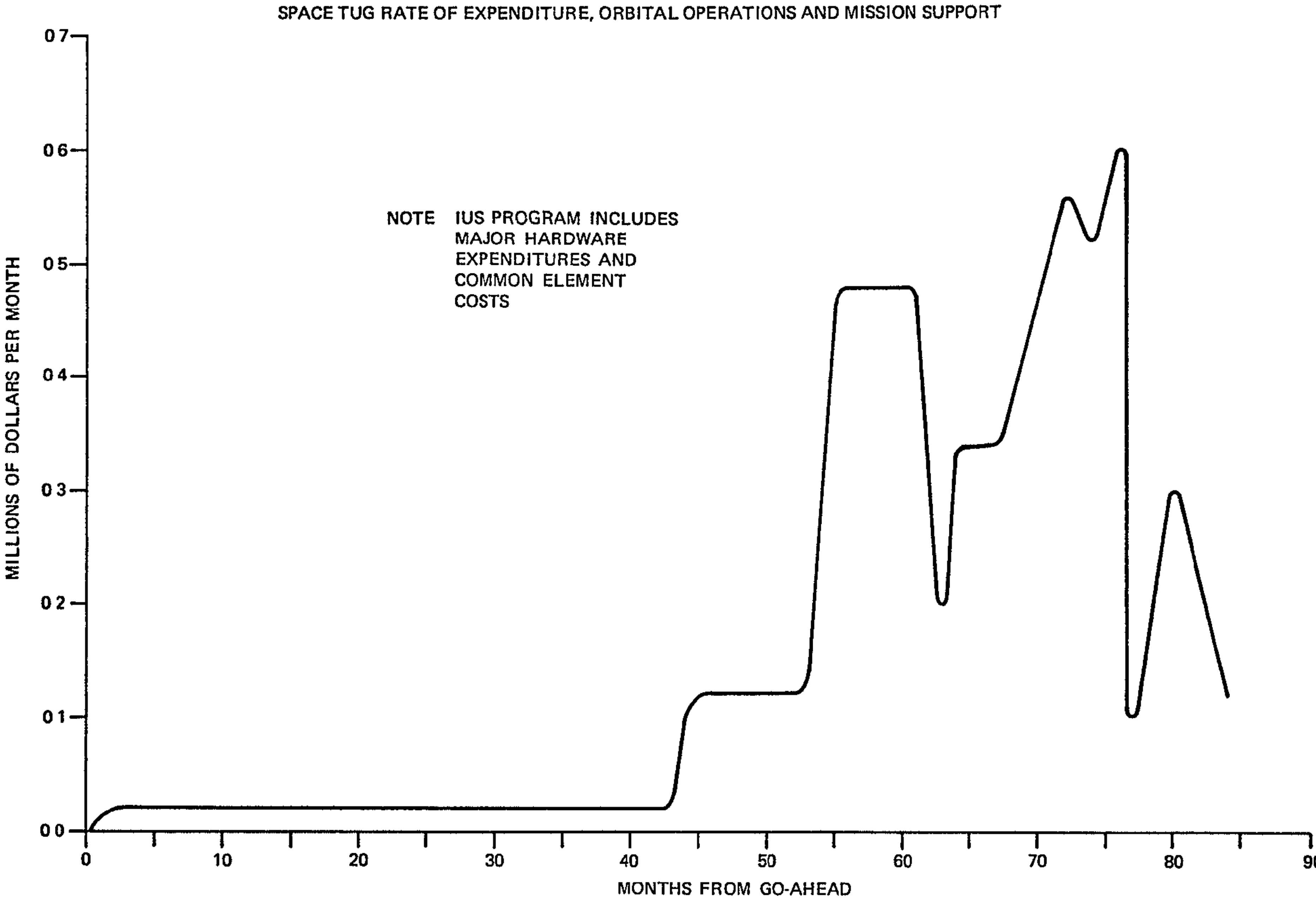

Figure 10.6 0-6. Space Tug DDT&E Rate of Expenditure Curve (OO/MS)

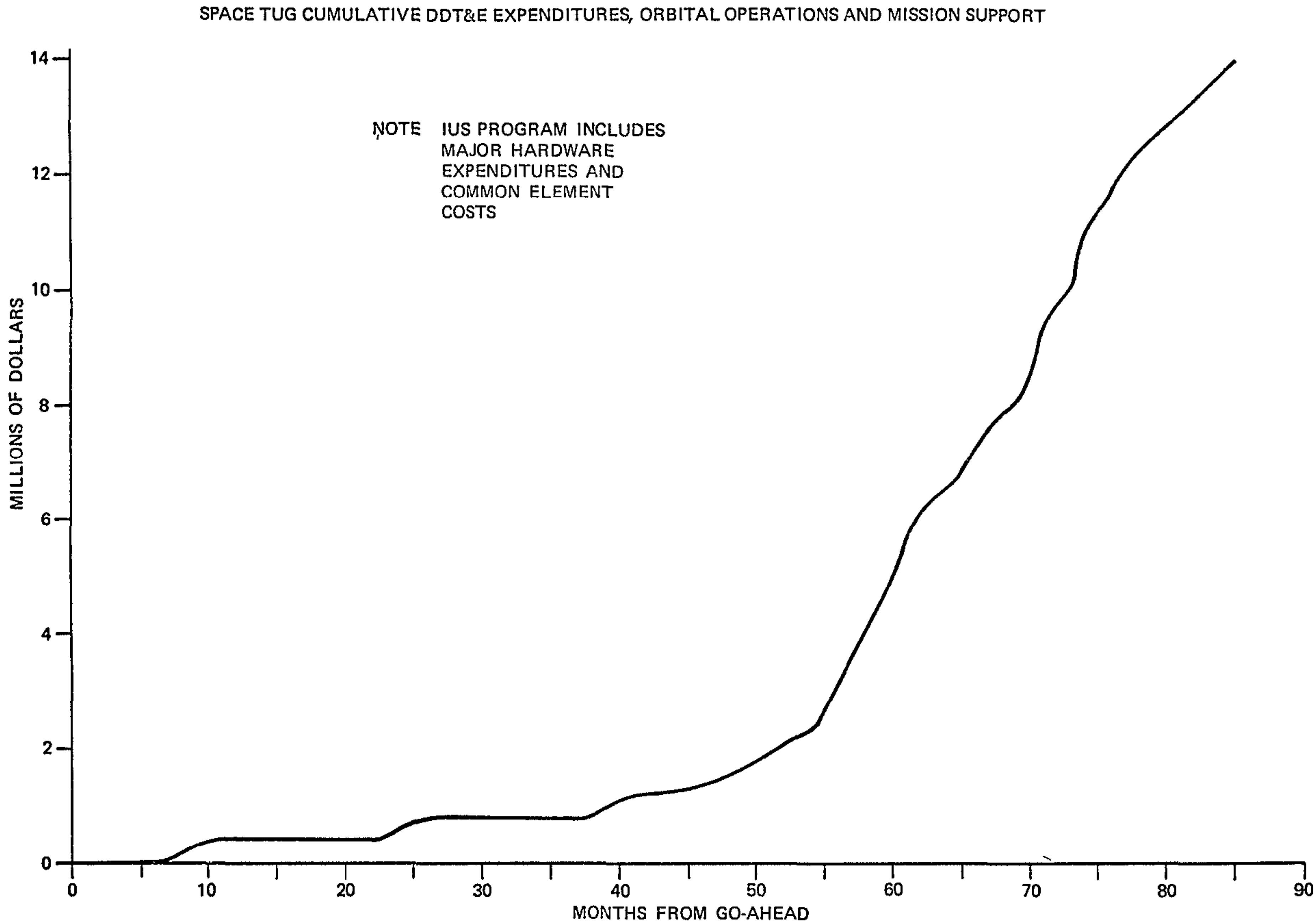

Figure 10.6 0-7 Space Tug Cumulative DDT&E Expenditures (OO/MS)

SCHEDULE OF RECURRING TASKS, ORBITAL OPERATIONS AND MISSION SUPPORT

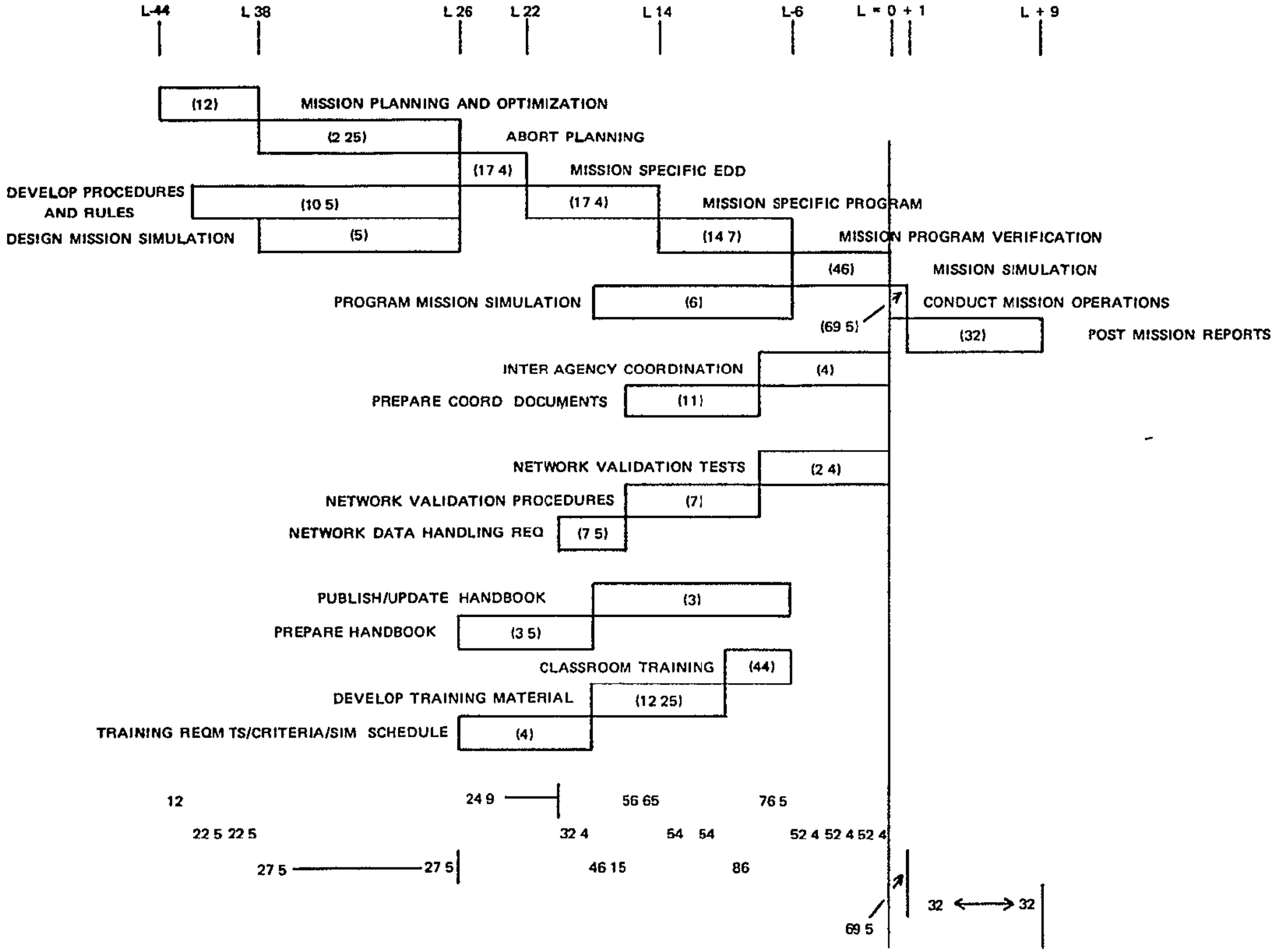

Figure 10.7 0-1 Schedule of Recurring Tasks (OO/MS)

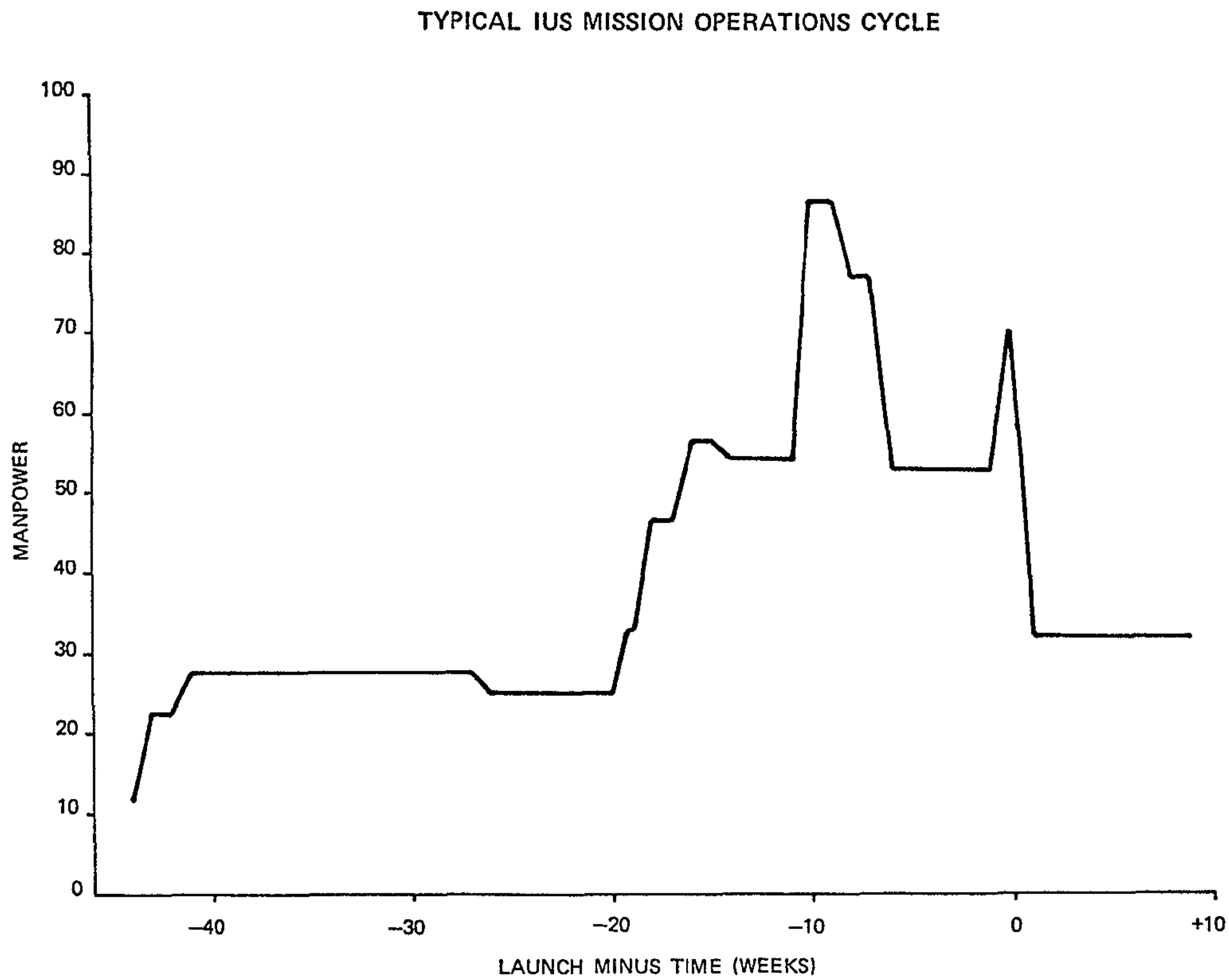

Figure 10 7 0-2 Typical Mission Operations Cycle

One is tempted to apply an exponential learning curve to the flight operation effort This should not be done, since the flight operations will be handled on a level of effort basis The learning curve could only apply to equivalent man months per month and could never fall below the level of sustaining flight control and flight support engineering personnel costs

Table 10 7 0-1 presents the cost summary for composite recurring IUS and Space Tug expenses Table 10.7.0-1 assumes there is no overlap of IUS and Space Tug operations Costs developed for the IUS program apply from April 1981 to November 1983, and the costs derived fro the Space Tug program apply from November 1983 to the end of the program. Examination of the mission model indicates a possibility that the IUS may continue to be utilized during a period which is predominately Space Tug oriented If such is the case, there will be no increase in recurring costs over the level required for Space Tug operations, under the assumption that the same personnel will be utilized to control the Space Tug as were utilized to control the IUS, and that the IUS unique ground software is available in off-line storage

Table 10.7 0-1 Composite IUS/Space Tug Recurring Expenses

- NO OVERLAP OF IUS AND SPACE TUG OPERATIONS
  - IUS RECURRING COSTS APPLY FROM APRIL 1981 TO NOVEMBER 1983
  - SPACE TUG RECURRING COSTS APPLY FROM NOVEMBER 1983 TO END OF PROGRAM
- IF IUS OPERATIONS OVERLAP SPACE TUG OPERATIONS,
  - NO INCREASE ABOVE SPACE TUG OPERATIONS COST LEVEL

RECURRING COSTS

ELEMENT	DOLLARS
FACILITY MAINTENANCE	19672
TOC SOFTWARE MAINTENANCE	1104000
DATA SYSTEM MAINTENANCE	134458
SUSTAINING TOC ENGINEERING	1584000
SUSTAINING TOC FLT ON TL ENGINEERING	1440000
NETWORK RENTAL	204755
TUG SOFTWARE MAINTENANCE	1008000
TOTAL	5494885
FACILITY MAINTENANCE	19872
TOC SOFTWARE MAINTENANCE	1200000
DATA SYSTEM MAINTENANCE	138795
SUSTAINING TOC ENGINEERING	1440000
SUSTAINING TOC FLT ON TL ENGINEERING	1440000
NETWORK RENTAL	26233
IUS SOFTWARE MAINTENANCE	1008000
TOTAL	5272900

POTENTIAL PROBLEM AREA SUMMARY 11

The Orbital Operations study defined items which appear to be potential problem areas for Tug operations and other areas require further consideration or analysis A summary of such items are included in this section

- JSC's Orbiter/Payload Interface is Information Only - JSC's Volume XIV Space Shuttle System Payload Accommodations Chg 7 was released but for information only This version of the avionics section finally contained enough detail to address interface problems JSC was contracted about a Tug interface problem and indicated the entire Orbiter/Payload interface was "INFO ONLY" It will be a baseline from which to solicit comment for approximately 1 year

  The Orbiter/Tug interface should be studied and defined from Tug "Orbital Operation" standpoint to another level of detail to further quantify the requirements to which the Orbiter must eventially be built IUS transition must also be considered and optimum data transfer techniques defined, such as addressed in the next concern

- Interface Data Transfer Concern, Orbiter and Ground/Payload Up Link Bit Rate and Coding Requirements Definition - The Orbiter to Payload command link bit rate is sometimes defined as 2 0 Kbps, 2 4 Kbps, 6 4 Kbps and 8 0 Kbps These numbers are all correct depending upon what portion of the total message is the basis for the bit rate The root is a 50 command per second capability This 50 times the 40 bit command data word cross the Orbiter/Payload interface is the 2 0 Kbps If the definition includes the address, there is 4 bits of vehicle address and 4 bits of system address which adds 4 Kbps and the bit rate is 2 4 Kbps Next the command bit stream is BCH encoded which adds 77 parity bits and 3 dummy bits for a total of 128 and the bit rate is 6 4 Kbps Before transmission a 32 bit sync is added which results in a 160 bit word and a 8 Kbps bit rate This is all based on a 50 command message per second rate of transfer

  The BCH coding scheme is the same as used on the ground before transmission to the Orbiter Therefore the Orbiter decodes the command and if the address identifies it as a payload command the GPC forwards it to the payload interface via the MDMs and PSPs. Within the PSP, (BCH) re-encoding takes place if the total transmission bit rate is to be 8 Kbps If it is something less, the re-encoding will be done within the GPC as specified by the payload This means the encoding will be custom designed for payloads and now is a software function This will typically lower the encoding overhead for the slower rates However, it must now be defined, coordinated with JSC implemented software and may or may not be the lowest cost approach

  Therefore, what is clearly required is an Uplink Command Requirement definition study to define attached and detached commanding, both in terms of bit rate max and coding required to ensure proper transmission Then, an implementation trade, to see how best to meet requirements for the least program cost

Retrieval of a Disabled Tug - The Orbital Operations study did not include the analysis for retrieval of a disabled Tug (or Spacecraft) if it is in an orbit which is acessable to the Orbiter An example would be the failure of the Tug prior to its first mainstage burn This area should be studied to determine if a retrieval capability for the Tug is justified.

- Spacecraft Orbiter Impacts - The Tug Orbiter software impacts were investigated by the study, but the Spacecraft software impacts on the Orbiter were not The Spacecraft impacts should be assessed to determine the total Tug and Spacecraft impacts on the Orbiter

- Tug Impacts TDRSS Usage - The TDRSS user support requirements will be varied For instance, the Tug 16 Kbps requirement can be met by the Multiple Access system However, a 64 Kbps requirement during burn periods may preclude the use of the MA system by the Tug, primarily because bandwidth requirements would limit the use of the TDRS MA system by other users The same reasoning applies to the onboard recorder dumps, which is expected to be at 64 on 256 Kbps The most obvious solution is to require the Tug to interface with the S-Band single access system during burns and onboard recorder dumps At this time the MA user can interface with the SSA system with a minimal hardware impact However, this should be pursued in greater detail due to the significance of the requirement See discussion in Section 8 3 4

- The Baseline Tracker Acquisition Range is Apparently Inadequate for Pre-TPI Acquisition - Small navigation dispersions and a TPI impulse budget larger than the examples shown in Section 7 2 may ease the requirement for longer acquisition ranges but additional analysis is required

- Final Braking Definition - The implementation of the final braking before Docking Inspection and Alignment commences may be implemented under phase-plane control, i e , a smooth distributed impulse range-rate solution rather than a discrete burn As mentioned previously in Section 7 2, the feasibility of this approach must be defined with more sophisticated techniques than were employed in this study

- Impulse Budget Refinement - Analysis of non-optimal Lambert transfers should be undertaken as soon as possible because that class is actually more likely than optimal transfers The APS impulse budget for rendezvous and docking appears to drive the rendezvous tracker acquisition range requirement Additional and continuing refinement of the impulse budget, therefore, is required

- Simulation of Tug Body Dynamics - A detailed simulation of Tug body dynamics during docking to assess the effects of slosh on APS fuel usage and the effect of impact dynamics on Tug translational and rotational control is required to support analysis of the docking parameters See Section 7 2

- Proposed Requirements - The following requirements have been identified from the analysis of the Space Tug operations and are proposed to be added to the baseline See Section 2 0

1 A system level checkout requirement is needed Consistent with Level II autonomy Tug design baseline and with the state-of-the-art in Built-in-Test-Equipment (BITE), it is a Tug requirement to be primarily responsible for system level check-out as part of redundancy management The Tug Operations Center (TOC) will be primarily responsible for detailed Tug status

2 A classified payload handling requirement is needed. In the event a classified payload is retrieved it may be desirable to remove part or all of it from the Tug while in the cargo bay Some form of requirement will be necessary to handle such a situation. In general, no requirement addresses just what the Orbiter is to do with classified payloads This situation could impact mission planning if the Tug were ever required to deploy an unclassified but retrieve a classified payload

3 Maintain LO_2 + LH_2 to run fuel cells for 4-5 hours following propellant dumps The fuel cells are required to power the communications, telemetry, IMU and DMS until after Tug recovery by the Orbiter

4 Autonomous navigation requires ILT or equivalent Autonomous navigation is cost effective because it is independent of ground support costs ILT is proven to be the most accurate means of navigation update

5 Rendezvous and Docking Sensor Range (75-100 NM) minimum @ TPI. This requirement results in minimum expenditure of APS fuel

6 Fuel Cells activated during prelaunch to supply Tug power thru ascent and on-orbit operations The Tug power requirements exceed that available from the Orbiter and therefore require full Tug mission duration use of its fuel cells.

7 Telemetry from Tug to Orbiter and Tug to Ground must be the same This will allow one set of software to be used to encode and decode the telemetry for the various types of processing that will be required

8 Uplink (command) formats from ground thru Orbiter to Tug and from ground to Tug must be the same This will allow use of one set of software and or hardware encoders and decoders on the ground and onboard the Orbiter and the Tug

9 Orbiter to Tug RF must be established prior to umbilical dis-connect This is required to assure the safety of the Orbiter and its ability to control the Tug once it is free flying

10 Design Goal - IUS and Tug, telemetry and command formats should be the same or similar This is required to allow ease of transition i.e , personnel training, reuse of some procedures,

reuse of software and or hardware encoders and decoders on the ground and onboard the Orbiter, the IUS and the Tug

11 360 degrees antennas radiation for both telemetry and command This is required for safety to allow minimum attitude constraint between Tug and the Orbiter (whose violation will result in communications dropouts) while the Tug is operating close to, and is a hazard to, the Orbiter

12 On-orbit target update capability is required As part of contingency planning, to accommodate a variety of partly failed hardware situations, it will be necessary to do a target update on-orbit

- Baseline Requirements Concerns - The following baseline requirements are those which can not be or are not being implemented With each stated requirement is given the reason for concern, the options to alleviate the concern and the recommendation to close out the issue

1 Requirement No 2 and 29

OTI-2-17-139 A Tug automatic caution and warning system will be provided to alert the Orbiter to hazardous conditions in the Tug when attached or within TBD miles of the Orbiter This system shall interface with the standard Orbiter caution and warning displays and warning devices

OTI-29-10-45 (1) All subsystems except primary structure and pressure vessels shall be designed to fail safe in the vicinity of the Shuttle Orbiter

(2) All safety subsystems shall be designed to fail operational in the vicinity of the Shuttle Orbiter

- Concern

  - Detached Tug C&W data flow path is simplex at Orbiter Payload Data Interleaver as presently defined

- Options

  - Orbiter design change to implement redundant data paths thru Payload Data Interleaver

- - Procedural change to implement an Orbiter evasive maneuver to safe distance and ground activation, checkout of Tug/Spacecraft

If checkout OK then proceed with mission.

If checkout not OK then ground will safe Tug/Spacecraft and Orbiter will retrieve Tug/Spacecraft if possible

- Recommendation

  - Procedural change provides satisfactory technical solution

2 Requirement No 3

OTI-3-17-140 Design Tug so it can be jettisoned in orbit by command from Orbiter or ground for emergency reasons Provide emergency deploy and release of Tug to Orbiter connections

- Concerns

  - Currently not in baseline design

  - IBM/GDC-I/MSFC have discussed issue and have assumed jettison equates to normal Tug deployment

  - What is minimum deploy time for emergency conditions?

  - Are there Tug system failures which can manifest themselves prior to the minimum deploy time?

- Recommendations

  - JSC/MSFC should define minimum deploy time for emergency conditions

  - Space Tug studies should define system failures that could occur prior to minimum time and design protection against identified failures

  Or

  - Delete Requirement No 3

3 Requirement No 20

OTI-20-10-51 The proper functioning of the interface between the STS and Tug shall be maintained under all nominal, contingency, and emergency operations of either the STS or the Tug

- Concern

  - Detached Tug data flow path is simplex at Orbiter Payload Data Interleaver

- Options

  - Orbiter design change to implement redundant data paths thru Payload Data Interleaver

- - Procedural change (same as Requirement No 2 and 29)

- Recommendation

  - Procedural change (same as Requirement No 2 and 29)

4 Requirement No 27

OTI-27-10-28 The Tug shall not initiate its propulsion system until a safe separation distance and attitude relationship between Orbiter and Tug is achieved The Tug propulsion system shall not cause impringement of exhaust gases that would be harmful to the Orbiter

- Concerns

  - APS will be activated shortly after physical deployment

  - It is assumed the requirement statement is applicable to main propulsion system only

- Recommendations

  - Restate requirement for application to main propulsion system only

5. Requirement No 44

OTI-44-10-63 Tug critical command and control circuitry shall be designed to be fail operational/fail safe as a minimum

- Concerns

  - Requirement statement for fail operational/fail safe stated in MSFC Baseline document

  - First Data Exchange recommendation was stated as "No Single Point Failure Shall Result in a Hazard Which Jeopardizes the Flight or Ground Crew"

  - No indication of fail safe design in Avionics or interface

- Recommendation

  - MSFC needs to restate current requirement for contractor guidance

6. <u>Requirement No 45</u>

OTI-45-10-63 Tug autonomous navigation commands for attitude control and translation maneuvers shall be disabled until a safe separation distance and compatible trajectories can be verified

- Concerns
  - APS (attitude hold) will be activated shortly after physical deployment
  - Requirement statement implies no commands for attitude holds
- Recommendation
  - Restate requirement to exclude attitude hold activation

REFERENCES 12

1	Space Tug Avionics Definition Study, Contract NAS8-31010	GDC
2	Space Tug/Shuttle Interface Compatibility Study, Contract NAS8-31012	GDC
3	IUS/Tug Payload Requirements Compatibility Study, Contract NAS8-31013	MDAC
4	Tug Fleet and Ground Operations Schedules and Controls, Contract NAS8-31011	Martin-Marietta
5	Space Shuttle Payload Accommodations, JSC 07700, Vol XIV	JSC
6	Space Shuttle Flight and Ground System, JSC 07700, Vol X	JSC
7	Payload Safety Requirements for National Space Transportation System	NASA HQ
8	Space Shuttle System Baseline Reference Mission, JSC - 07896	JSC
9	Space Tug Autonomy Analysis Study, Contract NAS8-30297	IBM
10	Baseline Space Tug System Requirements and Guidelines, MSFC 68M00039-1	MSFC
11	Tracking and Data Deploy Satellite System (TDRSS) Definition Phase Study Report	GSFC
12	The October 1973 Space Shuttle Traffic Model, NASA TMX-64751, Rev 2	NASA
13	Shuttle Sortie Payload Description, Vol II, Level B	MSFC
14	Summarized NASA Payload Description, Sortie Payload Level A	MSFC
15	Baseline Space Tug Ground Operations Verification, Analysis and Processing, MSFC 68M00039-4	MSFC
16	Baseline Space Tug Configuration Definition, MSFC 68M00039-2	MSFC

17 Baseline Space Tug Flight Operations, MSFC 68M00039-3 — MSFC

18. STDN User's Guide Baseline Document, STDN No 101 1, Rev 2 — GSFC

19 TDRS User's Guide, Rev 1 — GSFC

20. IUS/Tug Orbital Operations and Mission Support Study Technical Review September 1974, Contract NAS8-31009 — IBM

21 IUS/Tug Orbital Operations and Mission Support Study Space Tug Baseline Operations Plan (Preliminary) November 1974, Contract NAS8-31009 — IBM

22 IUS/Tug Orbital Operations and Mission Support Study Final Program Review April 1975, Contract NAS8-31009 — IBM

23 Payload Utilization of Tug Report (Volume 2) Contract NAS8-29743, June 1974 — MDAC

24 DoD/NASA System Impact Analysis (Study 2 1) Final Report, Vol 2 Study Results (Gross Abort Effects on STS Elements) Contract NASW-2472 — Aerospace

VOLUME III

APPENDIX A

BASELINE REQUIREMENTS DELETED DURING IUS/TUG ORBITAL OPERATIONS AND MISSION SUPPORT STUDY

May 1975

APPENDIX A

TABLE OF CONTENTS

APPENDIX A

1 0 ORBITER/TUG INTERFACE REQUIREMENTS DELETED

The following eighteen baseline requirements were among those listed early in this study for assessment, as having potential impact on the Orbiter/Tug interface design from an Orbital Operations standpoint The eighteen presented here were assessed and found to be operationally duplicates or having no impact on Orbital Operations functions They have been deleted from further consideration by this study Reasons for deletion accompany each requirement statement

OTI-13-10-66 Provisions shall be made for safing on command unused explosive devices aboard the Tug and safing verification sent to the Orbiter prior to retrieval

Reason for deletion - No explosive devices aboard Tug

OTI-16-10-63 Intentionally left blank.

Reason for deletion - No. 16 was a duplicate discovered early in study

OTI-31-10-45 Alternate or redundant means of performing a critical function shall be physically separated or protected such that an event which causes the loss of one means of performing the function will not result in the loss of alternate or redundant means

Reason for deletion - No operational requirement - physical design requirement

OTI-41-10-61 Redundant fluid or electric supply lines shall not be located near the primary line containing that commodity

Reason for deletion - No operational requirement - mechanical design requirement

OTI-46-10-63 Tug autonomous control commands for attitude control and translation maneuvers shall be disabled until a safe separation distance and compatible trajectories can be verified

Reason for deletion - Duplicate to No 18

OTI-47-10-64 Electrical umbilical disconnects between the Orbiter and the Tug and between the Tug and Spacecraft shall be separated from hazardous fluid disconnects, shall be qualified as explosion proof, and shall not have power applied during disconnect

Reason for deletion - No operational requirement - system design requirements.

OTI-48-10-64 Power circuits shall be separated from critical pyrotechnic circuits within a cable or wire bundle

Reason for deletion - No operational requirement - no pyrotechnics

OTI-49-10-64 Tug structure shall be grounded to Orbiter structure to prevent electrostatic charge buildup and an electrical shock hazard Within the Tug grounding shall be such as to preclude an electrical shock

Reason for deletion - No operational requirement - electrical design requirement

OTI-50-10-64 Safety critical electrical and electronic components shall be potted, hermetically sealed or similarly protected against the effects of liquid leakage, moisture condensation, vibration and arcing contacts

Reason for deletion - No operational requirement - packaging requirement

OTI-51-10-64 Capability shall be provided for static discharge between Tug and Orbiter and between the Tug and Spacecraft.

Reason for deletion - No operational requirement - electrical design requirement

OTI-52-10-64 The return of current to the power source shall be accomplished by means other than the Tug structure.

Reason for deletion - No operational requirement - electrical design requirement.

TOI-53-10-64 Safety critical control circuits shall be capable of being verified.

Reason for deletion - Duplicate to No 15

OTI-54-10-65 The arming of pyrotechnic devices shall be protected against accidental operations

Reason for deletion - No pyrotechnics on Tug.

OTI-55-10-65 Positive indications of Tug electrical systems shut down status shall be provided to the Orbiter flight crew, prior to retrieval

Reason for deletion - Duplicate to No. 14

OTI-56-10-71 Provisions shall be made for verifying critical Spacecraft systems readiness before activation

Reason for deletion - No Tug/Orbiter operational requirement - SC system verification requirement

OTI-58-10-74 No single operation shall result in flow of propellant through the Spacecraft propulsion system The APS shall be inhibited while in the Orbiter payload bay

Reason for deletion - No Tug/Orbiter operational requirement - SC propellant system requirement and SC/Tug interlock requirement.

OTI-59-10-74 Spacecraft sequencing control for attitude hold and main engine starting sequence shall be remotely code commanded by the Orbiter crew or ground control Interlocks shall be provided to prevent inadvertent operations of the Spacecraft while in the Orbiter payload bay or during the deployment phase of operation

Reason for deletion - No Tug/Orbiter operational requirement - SC/Orbiter interface while detached and SC/Tug interlock requirement

OTI-63-10-77 Provisions shall be included for Spacecraft caution and warning functions which will provide both audible and visual warning to Orbiter crew of hazardous situations while the Spacecraft is aboard the Orbiter or being deployed

Reason for deletion - Redundant with requirement No 12

2 0 PAYLOAD/TUG INTERFACE REQUIREMENTS DELETED

The following 21 baseline requirements were among those listed early in this study for assessment, as having potential impact on the Payload/Tug interface design from an Orbital Operations standpoint. The 21 presented here were assessed and found to be operationally duplicates or having no impact on Orbital Operations functions They have been deleted from further consideration by this study Reasons for deletion accompany each requirement statement

PTI-5-10-20 The Tug (after Orbiter release) shall have a limited capability to relay SC systems status to the SC operations center or relay SC operations center commands to the SC

Reason for deletion - Operationally contained in requirement No 7

PTI-10-10-20 The Tug shall relay via the Orbiter SC operations center control commands to the SC as required for mission preparations Orbiter safety related commands to the SC shall be relayed to the SC

Reason for deletion - Operationally contained in requirement No 7

PTI-15-10-45 Alternate or redundant means of performing a critical function shall be physically separated or protected such that an event which causes the loss of one means of performing the function will not result in the loss of alternate or redundant means.

Reason for deletion - System design requirement only

PTI-16-10-45 Mission critical single failure points will be minimized to the maximum extent possible

Reason for deletion - System design goal only

PTI-17-10-46 Isolation of anomalies of mission and crew essential functions will be provided to assure a failure will not propagate across any interface

Reason for deletion - System design goal only

PTI-18-10-54 All mechanical, electrical and fluid connections between the Tug and Spacecraft and Orbiter shall be fail safe.

Reason for deletion - System design requirement only

PTI-19-10-70 Any Spacecraft subsystem operation which impacts safety during the launch and entry phases shall be monitored via C&W (caution and warning) and controlled from the Orbiter flight station

Reason for deletion - This requirement is contained in requirements No 9 and No 13

PTI-21-10-70 Provisions shall be made to confirm that all safety critical Spacecraft/Tug and Spacecraft/Orbiter interfaces are securely connected

Reason for deletion - Redundant with requirement No 2

PTI-22-10-61 Redundant fluid or electric supply lines shall not be located near the primary line containing that commodity

Reason for deletion - Mechanical layout requirement only

PTI-23-10-64 Capability shall be provided for static discharge between Tug and Orbiter and between the Tug and Spacecraft

Reason for deletion - Electrical system design requirement only

PTI-24-10-64 The return of current to the power source shall be accomplished by means other than the Tug structure

Reason for deletion - Electrical system design requirement only

PTI-25-10-64 Electrical umbilical disconnects between the Orbiter and the Tug and between the Tug and Spacecraft shall be separated from hazardous fluid disconnects, shall be qualified as explosion proof, and shall not have power applied during disconnect

Reason for deletion - Mechanical design requirement only

PTI-26-10-64 Power circuits shall be separated from critical pyrotechnic circuits within a cable or wire bundle

Reason for deletion - Electrical cable layout requirement only

PTI-27-10-76 Spacecraft should be grounded to Tug structure to prevent electrostatic charge buildup and an electrical shock hazard Within the Spacecraft, grounding shall be such as to preclude an electrical shock A positive ground shall exist from the Spacecraft to the Orbiter structure

Reason for deletion - Electrical system design requirement only

PTI-28-10-77 Provision shall be included for Spacecraft caution and warning functions which will provide both audible and visual warning to Orbiter crew of hazardous situations while the Spacecraft is aboard the Orbiter or being deployed

Reason for deletion - Requirement is redundant with No 20

PTI-29-10-78 Sequence logic and pyrotechnic firing circuits of the Spacecraft shall be capable of sustaining a failure without causing a hazard to the flight crew or damage to the Orbiter, Tug or other Spacecraft Spacecraft pyrotechnic logic circuits shall receive power from a source other than the pyrotechnic batteries

Reason for deletion - Electrical system design requirement only

PTI-31-10-78 Pyrotechnic initiation circuits shall be routed separately from power circuits

Reason for deletion - Electrical layout requirement only

PTI-40-10-74 No single operation shall result in flow of propellant through the Spacecraft propulsion system The APS shall be inhibited while in the Orbiter payload bay

Reason for deletion - Implicit in requirement No 36

PTI-41-10-74 Spacecraft sequencing control for attitude hold and main engine starting sequence shall be remotely code commanded by the Orbiter crew or ground control. Interlocks shall be provided to prevent inadvertent operations of the Spacecraft while in the Orbiter payload bay or during the deployment phase of operation

Reason for deletion - Redundant to requirement No 36

PTI-42-10-71 Spacecraft operations and energy levels shall be minimized while aboard or near (TBD) the Orbiter.

Reason for deletion - System design goal only

PTI-43-10-71 Provision shall be made for verifying critical Spacecraft systems readiness before activation.

Reason for deletion - Redundant to requirement No 3

3 0 TUG/GROUND INTERFACE REQUIREMENTS DELETED

The following nine baseline requirements were among those listed early in the study for assessment, as having potential impact on the Tug/Ground interface design from an Orbital Operations standpoint The nine presented here were assessed and found to be operationally duplicates or having no impact on Orbital Oerations functions They have been deleted from further consideration by this study Reasons for deletion accompany each requirement statement.

TGI-7-10-58 The planned attitudes of the Tug during release and separation from the Orbiter shall be such that the attitude control engines at no time accelerates the vehicle towards the Orbiter

Reason for deletion - This requirement is first placed on mission planning then executed by the Tug GN&C System

TGI-8-10-58 Tug attitude control or Tug main engine thrust shall not be used for initial separation of the Tug to a safe distance (TBD) from the Orbiter

Reason for deletion - This requirement is met by the Orbiter moving away from the Tug

TGI-26-10-45 Mission critical single failure points will be minimized to the maximum extent possible

Reason for deletion - This is a design goal only

TGI-27-10-45 Alternate or redundant means of performing a critical function shall be physically separated or protected such that an event which causes the loss of one means of performing the function will not result in the loss of alternate or redundant means

Reason for deletion - Mechanical layout design requirement only

TGI-28-10-46 Isolation of anomalies of mission and crew essential functions will be provided to assure a failure will not propagate across any interface

Reason for deletion - System design requirement only

TGI-29-10-51 The proper functioning of the interface between the STS and Tug shall be maintained under all nominal, contingency, and emergency operations of either the STS or the Tug

Reason for deletion - Requirement on the Orbiter/Tug interface

TGI-30-10-51 No single Tug failure shall result in a hazard which jeopardizes the flight or ground crews of the Shuttle, general public, public/private property and the ecology

Reason for deletion - Contained within the scope of requirement No 33

TGI-31-10-54 As a minimum, Tug shall be designed to sustain a failure and retain the capability to successfully terminate the Tug functions

without injuring flight personnel or damaging the Orbiter or other payloads (fail-safe)

Reason for deletion - Tug internal design requirement

TGI-32-10-54 Tug operations and energy levels shall be held to a minimum while aboard or in the near vicinity of the Orbiter

Reason for deletion - System design goal only

4 0 TUG SYSTEMS REQUIREMENTS DELETED

The following twelve baseline requirements were among those listed early in this study for assessment, as having potential impact on the Tug Systems design from an Orbital Operations standpoint The twelve presented here were assessed and found to be operationally duplicates or having no impact on Orbital Operations functions They have been deleted from further consideration by this study Reasons for deletion accompany each requirement statement

TS-26-10-58 Tug shall be switched from command control to internal attitude control after Orbiter has been sufficiently moved (TBD) so that no Tug attitude change could result in collision with the Orbiter

Reason for deletion - This requirement is operationally similar to requirement No 25

TS-30-10-46 Isolation of anomalies of mission and crew essential functions will be provided to assure a failure will not propagate across any interface

Reason for deletion - System design goal only

TS-39-10-28 The Tug shall not initiate its propulsion system until a safe separation distance and attitude relationship between Orbiter and Tug is achieved. The Tug propulsion system shall not cause impingement of exhaust gases that would be harmful to the Orbiter

Reason for deletion - This requirement is operationally similar to requirement No 25

TS-41-10-65 Electrical wiring must not be routed against or around sharp edges

Reason for deletion - Electrical wiring layout requirement only

TS-42-10-65 Electrical wiring must not be in contact with flammable fluids

Reason for deletion - Electrical wiring layout requirement only

TS-43-10-65 Electrical circuits which will be cut by guillotine cutters must be deadfaced

Reason for deletion - Electrical system requirement only.

TS-45-10-75 Spacecraft critical command and control circuitry shall be designed to be fail-operational/fail-safe as a minimum

Reason for deletion - This is a Spacecraft requirement only

TS-46-10-66 Sequence logic and pyrotechnic firing circuits shall be at least dual redundant

Reason for deletion - There are no pyrotechnics planned for Tug

TS-47-10-66 Pyrotechnic logic circuits shall receive power from a source

other than the pyrotechnic initiation source

Reason for deletion - There are no pyrotechnics planned for Tug

TS-48-10-66 Pyrotechnic firing circuits shall be protected from electrostatic charge buildup

Reason for deletion - There are no pyrotechnics planned for Tug

TS-49-10-66 Sequence logic and pyrotechnic firing circuits shall be capable of sustaining a failure without causing a hazard to the flight crew or damage to the Orbiter or other payloads

Reason for deletion - There are no pyrotechnics planned for Tug

TS-50-10-66 To insure firing of safety critical pyrotechnic devices in parallel, the design of pyrotechnic circuits must prevent constant power drain in the event the device short circuits upon activation

Reason for deletion - There are no pyrotechnics planned for Tug

VOLUME III

APPENDIX B

SPACE SHUTTLE C&W DEFINITION AS RELATED TO SPACE TUG

IBM

November 1974

TABLE OF CONTENTS

TABLE OF CONTENTS
(CONTINUED)

FIGURES

APPENDIX B

SPACE SHUTTLE C&W DEFINITION AS RELATED TO SPACE TUG

Purpose

The purpose of this definition is to clear the confusion that exists every time the C&W system is addressed In the effort of putting this together it became apparent there is not a firm definition This will therefore indicate what appears to be the present design and identify issues known to be uncertain

Scope

This definition will be largely the Space Shuttle defining its C&W system, because the payload is merely a user. It will show how this system relates to the TUG C&W requirements. Actual numbers of C&W parameters (Orbiter System or TUG System) are of course estimates and presently even the capability is uncertain

1 0 ANOMALY CATEGORIZATION

Vehicle and subsystem anomalies that require flight crew attention are classed in the following categories

Emergency - condition creates immediate crew hazard (e g fire or rapid depressurization)

Caution and Warning - actual or impending anomalous condition of subsystem element (e.g H_2 pressure or O_2 pressure) (Defined Tug Anomalies Fall Here)

Advisory - affects parameters other than the critical parameters (e g loss of redundant element)

2 0 C&W SYSTEM REQUIREMENTS

MONITOR VEHICLE SUBSYSTEMS FOR MALFUNCTIONS

ALERT CREW TO EXISTENCE OF MALFUNCTIONS WITH
VISUAL AND AURAL ALARMS

PROVIDE INFORMATION AS TO MALFUNCTION NATURE, LOCATION AND CRITICALITY

ANNUNCIATORS WILL
SEPARATE BETWEEN VARIOUS PRIORITY ANNUNCIATIONS, BE
CENTRALLY LOCATED AND
DUAL REDUNDANT

GENERATE MASTER ALARM COINCIDENT WITH C&W ANNUNCIATION

PROVIDE SIGNAL FILTERING & DELAY PROVISIONS TO PREVENT TRIGGERING ON SHORT TRANSIENTS & NOISE

RETAIN ID OF SIGNALS TRIGGERING ALARM

PROVIDE MODE WHEREBY ANNUNCIATORS ARE INHIBITED (ACKNOWLEDGE MODE), ILLUMINATES WHEN MASTER ALARM SWITCH DEPRESSED

PROVIDE SPECIFIC INPUT INHIBIT

TRIGGERING ON ONE INPUT SHALL NOT PREVENT TRIGGERING FROM ANOTHER INPUT

AURAL ALARM VOLUME PREFLIGHT ADJUSTABLE

NO SINGLE C&W ELECTRONICS FAILURE SHALL AFFECT RESPONSE TO MORE THAN ONE INPUT

SHALL BE DIGITAL PROCESSOR WITH CAPABILITY FOR IN-VEHICLE C/W LIMIT CHANGES ON THE GROUND & IN FLIGHT

3 0 CATEGORY MECHANIZATION SUMMARY

EMERGENCY CONDITIONS

- INDEPENDENT, REDUNDANT SYSTEMS EMPLOYING DEDICATED SENSORS, DETECTORS, VISIBLE/AUDIBLE ALARMS

CAUTION & WARNING CONDITIONS

- PRIMARILY BY DEDICATED HARDWARE C&W SUBSYSTEM
- SECONDARILY BY BACK UP C&W SOFTWARE PERFORMANCE MONITOR FUNCTION
- PRIMARY & BACKUP C&W EMPLOY.
  - OPERATIONAL SENSORS
  - VISIBLE/AUDIBLE ALARMS
  - FAULT IDENTIFICATION (C&W STATUS PANEL)
  - INHIBIT STATUS DISPLAY

ADVISORY CONDITIONS

- DETECTED BY C&W SOFTWARE PERFORMANCE MONITOR
- UTILIZES
  - OPERATIONAL SENSORS
  - VISIBLE ALARM (SM ADVISORY LITE)
  - OPTIONAL AUDIBLE ALARM
  - CRT FOR FAULT IDENTIFICATION & INHIBIT STATUS

4 0 ORBITER C&W SYSTEM

The system is pictured in Figure 1

4 1 SYSTEM ANOMALY INPUT CAPABILITY

4 1 1 EMERGENCY CONDITIONS

Two types identified, Maximum capability unknown Some require special lites, some use C&W annunciation

4 1 2 ORBITER SYSTEM STATUS

120 FUNCTIONAL INPUTS, MIX OF ANALOG AND DISCRETE TYPES
FED IN PARALLEL TO BACKUP C&W PERFORMANCE MONITOR

4 1 3 BACKUP C&W

PERFORMANCE MONITOR (SOFTWARE DERIVED) FROM SAME 120 FUNCTIONS ABOVE
ACTIVATES 1 OF THE 40 CWA LIGHTS
SETS MASTER ALARM, CAUTION & WARNING TONES
MANUAL RESET REQUIRED

4 2 SYSTEM OUTPUT CAPABILITY

4 2.1 AURAL ALARMS (ALL DUAL REDUNDANT)

SIREN

ACTIVATES SIREN OUTPUT AND RESET WHEN SIREN INPUT IS REMOVED

KLAXON

ACTIVATES KLAXON OUTPUT AND RESET WHEN KLAXON INPUT IS REMOVED

BACKUP C&W

ACTIVATES WITH BACKUP C&W (PERFORMANCE MONITOR) OUTPUT AND RESET WHEN BACKUP C&W OUTPUT IS REMOVED

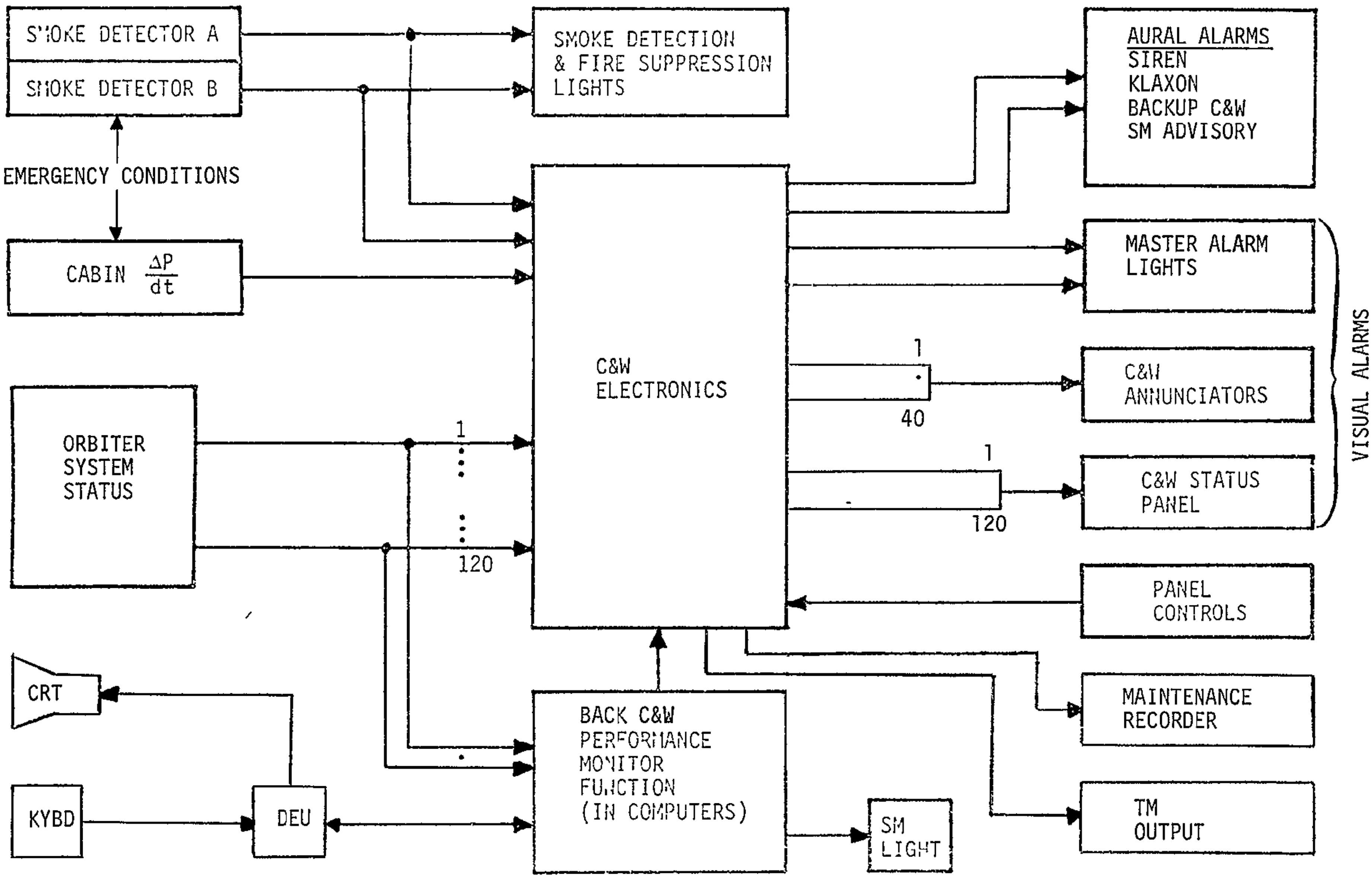

Figure 1   Orbiter C&W System

SM ADVISORY

ACTIVATES THE SM ADVISORY TONE (550 Hz) AND RESET WHEN SM IS REMOVED

4 2 2 <u>VISUAL ALARMS</u>

MASTER ALARM LITES DUAL REDUNDANT

C&W ANNUNCIATORS

39 PARALLEL SYSTEM OUTPUTS TO THE CWA

1 BU C&W OUTPUT TO THE CWA

C&W STATUS PANEL

120 CODED OUTPUTS FOR DISPLAY ON THE CWS

4 2 3 <u>MISC OUTPUTS</u>

MAINTENANCE RECORDER

START COMMAND TO THE MAINTENANCE RECORDER COINCIDENT WITH MASTER ALARM ACTIVATION

TM OUTPUT

SIGNAL TO THE TELEMETRY SYSTEM COINCIDENT WITH MASTER ALARM ACTIVATION REMAINS ON UNTIL MASTER ALARM IS RESET

4 3 <u>SYSTEM PANEL CONTROLS</u>

CHANNEL SELECT

THUMBWHEEL SWITCH WITH BCD OUTPUT SELECTS ONE OF THE 120 INPUT CHANNELS

UPPER/LOWER LIMIT

TOGGLE SWITCH

SELECTS THE UPPER OR LOWER LIMIT TO BE CHANGED OR READ

LIMIT VALUE SELECT

THUMBWHEEL SWITCH WITH BCD OUTPUT SELECTS NEW LIMIT VALUE

LIMIT SET

MOMENTARY TOGGLE SWITCH

ENTERS THE NEW LIMIT VALUE FOR THE SELECTED INPUT

CHANNEL INHIBIT ON/OFF

MOMENTARY TOGGLE SWITCH

INHIBITS THE CHANNEL SELECT THUMBWHEEL (ON)

REMOVES INHIBIT ON THE SELECTED CHANNEL (OFF)

LIMIT READ

MOMENTARY TOGGLE SWITCH

COMMENTS READOUT OF ACTIVE LIMIT VALUE FOR SELECTED INPUT

MEMORY READ A (FORE)

DISPLAYS ALL C&W ANNUNCIATIONS SINCE LAST MEMORY CLEAR COMMAND ON FWD ANNUNCIATOR PANEL (CWA)

MEMORY READ B (AFT)

DISPLAYS ALL OUT-OF-LIMIT INPUTS SINCE LAST MEMORY CLEAR COMMAND ON AFT STATUS PANEL (CWS)

MEMORY CLEAR

CLEARS STORED IDENTIFICATION OF OUT-OF-LIMIT INPUTS

TRIP STATUS

PROVIDES REAL-TIME READOUT OF OUT-OF-LIMIT INPUTS ON THE CWS

INHIBIT STATUS

IDENTIFIES INPUTS THAT ARE INHIBITED ON THE CWS

4 4 CREW INTERACTION WITH PERFORMANCE MONITOR FUNCTION

TEST LIMITS FOR BACKUP C&W ALTERABLE WITH CRT/KYBD
DETAILS OF ANOMALY AVAILABLE WITH CRT/KYBD

4 5 BACKUP C&W AND SM ADVISORY RELATIONSHIP

BACKUP C&W - PERFORMANCE MONITORING SOFTWARE

- SAME PARAMETERS AS HARDWARE C&W
- SAME LIMITS AS HARDWARE C&W
- UTILIZES C&W ELECTRONICS FOR
  - AUDIBLE - TONE
  - VISUAL - LIGHTS
- SEPARATE PATH IN C&W ELECTRONICS

SM ADVISORY - SOFTWARE

- LOWER LEVEL PARAMETERS
- UTILIZES C&W ELECTRONICS FOR
  - AUDIBLE - TONE
- RESET VIA KEYBOARD
- LATCH/UNLATCH - IN SOFTWARE

4 6 C&W ELECTRONICS REDUNDANCY SUMMARY

CEI REQUIREMENT STATES THAT "NO SINGLE C&W ELECTRONICS FAILURE SHALL AFFECT RESPONSE TO MORE THAN ONE INPUT "

C&W ELECTRONICS MULTIPLEXES 120 INPUTS, PERFORMS ANALOG COMPARISON VIA SINGLE COMPARATOR & LOGICALLY OPERATES ON SINGLE SERIAL DATA STREAM

SOFTWARE BACKUP C&W PROVIDES REDUNDANCY BY INDEPENDENTLY MONITORING SAME PARAMETERS AS C&W ELECTRONICS AND DRIVES SEPARATE ANNUNCIATOR NO 40

C&W ELECTRONICS FUNCTIONS REQUIRED FOR SOFTWARE BACKUP ARE REDUNDANT MASTER ALARM AND TONE GENERATOR

See Figure 2 C&W System Redundancy Implementation

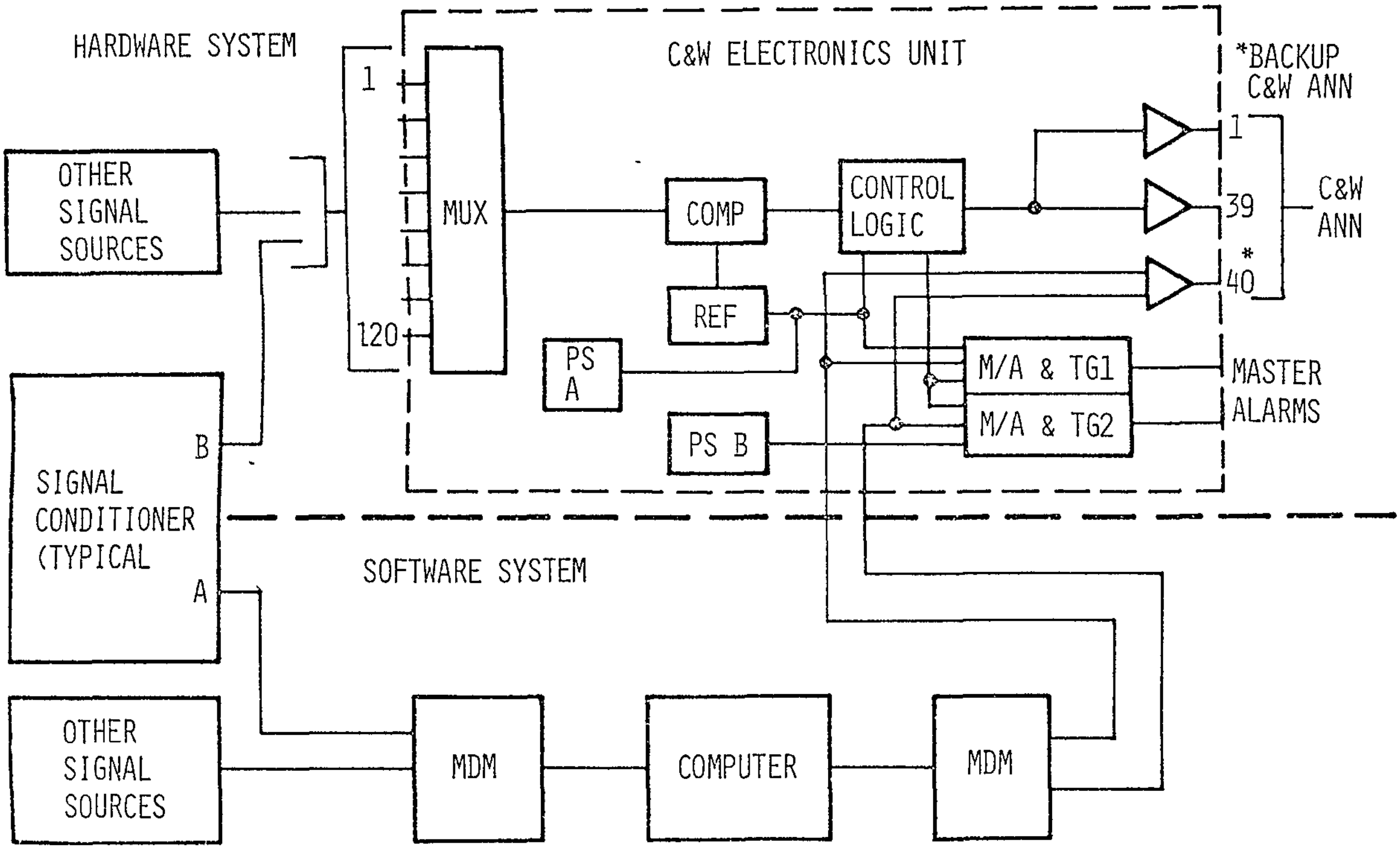

Figure 2 C&W System Redundancy Implementation

4 7 ORBITER 101 C&W INPUTS & ANNUNCIATORS

ORBITER SYSTEM STATUS TO C&W	ANNUNCIATORS
H_2 TANK ASSY 1 PRESSURE	H_2 PRESSURE
H_2 TANK ASSY 2 PRESSURE	
O_2 TANK ASSY 1 PRESSURE	O_2 PRESSURE
O_2 TANK ASSY 2 PRESSURE	
STACK COOLANT OUTLET TEMP	FUEL CELL 1
O_2 REACTANT VALVE-CLOSED	
H_2 REACTANT VALVE-CLOSED	
COOLANT PUMP STATUS	
STACK COOLANT OUTLET TEMP	FUEL CELL 2
O_2 REACTANT VALVE-CLOSED	
H_2 REACTANT VALVE-CLOSED	
COOLANT PUMP STATUS	
STACK COOLANT OUTLET TEMP	FUEL CELL 3
O_2 REACTANT VALVE-CLOSED	
H_2 REACTANT VALVE-CLOSED	
COOLANT PUMP STATUS	
HYD SYS 1 SUPPLY PRESSURE	HYD PRESSURE
HYD SYS 2 SUPPLY PRESSURE	
HYD SYS 3 SUPPLY PRESSURE	
HYD SYS 1 RESERVOIR LEVEL LOW	HYD QUANTITY
HYD SYS 2 RESERVOIR LEVEL LOW	
HYD SYS 3 RESERVOIR LEVEL LOW	

ORBITER SYSTEM STATUS TO C&W	ANNUNCIATORS
MAIN BUS A UNDERVOLT	MN A
MAIN BUS B UNDERVOLT	MN B
MAIN BUS C UNDERVOLT	MN C
AC BUS 1 OVERVOLT/UNDERVOLT	AC 1
AC BUS 2 OVERVOLT/UNDERVOLT	AC 2
AC BUS 3 OVERVOLT/UNDERVOLT	AC 3
AC BUS 1 OVERLOAD	AC 1 O LOAD
AC BUS 2 OVERLOAD	AC 2 O LOAD
AC BUS 3 OVERLOAD	AC 3 O LOAD
FCS FAILURE A	FCS
FCS FAILURE B	
C&W ELECTRONICS FAILURE	C&W FAIL
PMS ALARM A	BACKUP C&W
PMS ALARM B	
GPC 1 FAILURE	COMPUTER
GPC 2 FAILURE	
GPC 3 FAILURE	
GPC 4 FAILURE	
GPC 5 FAILURE	
G&N FAILURE A	GNC
G&N FAILURE B	
FLIGHT CONTROL SYS SATURATION A	CONTROL SATURATION
FLIGHT CONTROL SYS SATURATION B	

4 7 ORBITER 101 C&W INPUTS & ANNUNCIATORS (CONTINUED)

ORBITER SYSTEM STATUS TO C&W	ANNUNCIATORS
APU 1 TURBINE EXHAUST OVER-TEMP	APU 1
APU 2 TURBINE EXHAUST OVER-TEMP	APU 2
APU 3 TURBINE EXHAUST OVER-TEMP	APU 3
CABIN AIR FLOW RATE	AIRFLOW
CABIN PRESSURE	CABIN PRESSURE

5 0 ORBITER/PAYLOAD C&W SYSTEM ACCOMMODATIONS AND INTERPLAY

As shown in Figure 3, 50 C&W data channels (analog and/or discrete) from the payload interface input to a comparator in the payload C&W electronics unit Upon detection of an out-of-tolerance condition in one of the 50 inputs, the payload C&W electronics will active an individual light in the payload status board and the appropriate annunciator module in the payload C&W Annunciator Matrix The payload C&W electronics also provides outputs for starting the maintenance recorder and master alarm Up to TBD comparator outputs can be OR'd (pre-mission) to activate a single annunciator of the 25 available in the payload C&W annunciator matrix As shown in Figure 3, one annunciator is dedicated to the backup C&W, Performance Monitoring Derived Function. The 25 outputs of the combination logic OR-gates can be OR'd (pre-mission) in any desired combinations to activate up to 5 lights reserved in the payload C&W annunciator panel The five (5) payload outputs may be OR'd to a single "payload" annunciator reserved in the orbiter C&W matrix The payload C&W matrix will be used to identify which payload as well as system/parameter is out of tolerance

NOTE There is a current effort to combine the Orbiter C&W Electronics Unit and the Payload C&W Electronics Unit The Input/Output capability is therefore uncertain at this time

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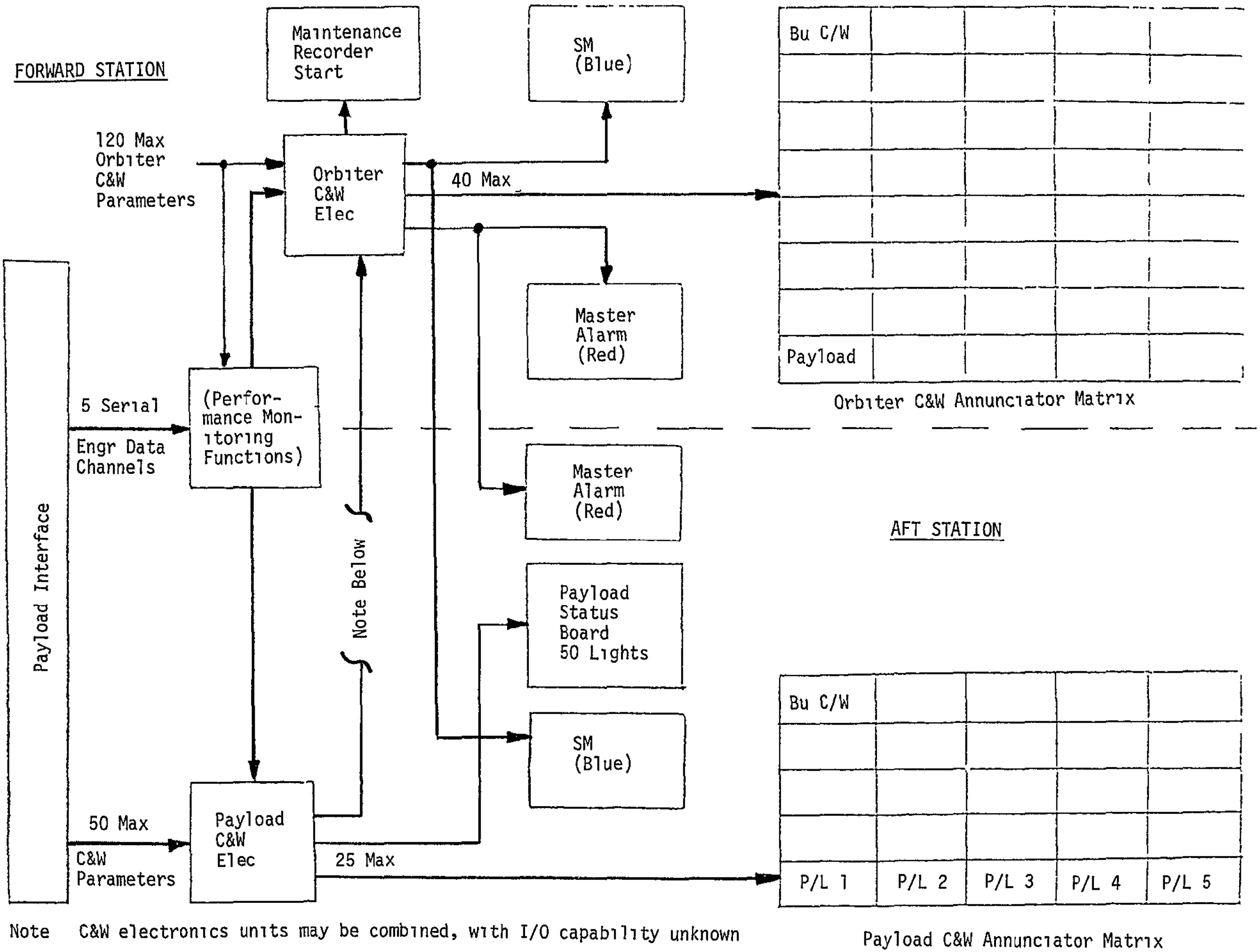

Figure 3 Payload Accommodations C&W Data Flow Diagram

6 0 CAUTION AND WARNING IMPLEMENTATION FOR THE TUG PAYLOAD

Each C&W parameter is monitored by two independent transducers and subsequent data paths Figure 4 illustrates the C&W interfaces

6 1 PRIMARY C&W PATH

One transducer is hardwired to the C&W electronics where it is monitored and limit checked against preprogrammed limits If the parameter exceeds its preset limits then an alarm is sounded and a titled indicator light corresponding to the affected parameter is illuminated on the C&W panels at the crew stations Any payload C&W indicator that is activated on the AFT station panels will result in the payload C&W light being illuminated on the forward crew station C&W panels This "hardwired" path through the C&W electronics constitutes the primary C&W path

6.2 SECONDARY C&W PATH

The second transducer is accessed either by the Tug data management system (DMS) and output to the orbiter PDI or is output directly across the interface into the MDM's dedicated to payload support This parameter is accessed by the GPC performance monitor function where it is limit checked against preprogrammed C&W limits An out-of-limit condition detected by this function will cause the GPC to illuminate the backup C&W indication at the FORWARD and AFT stations. The payload light will also be illuminated at the forward station

6 3 SYSTEM OPERATION

During nominal operation of the C&W system both the titled indicator from the primary path and the backup indicator from the GPC system will be illuminated Illumination of either singly is grounds for suspicion of a C&W problem If only the C&W backup indicator is illuminated then the crew must call up a display of C&W parameters to determine the cause of the C&W condition This call up and display will be accomplished via the display and keyboard located at either station

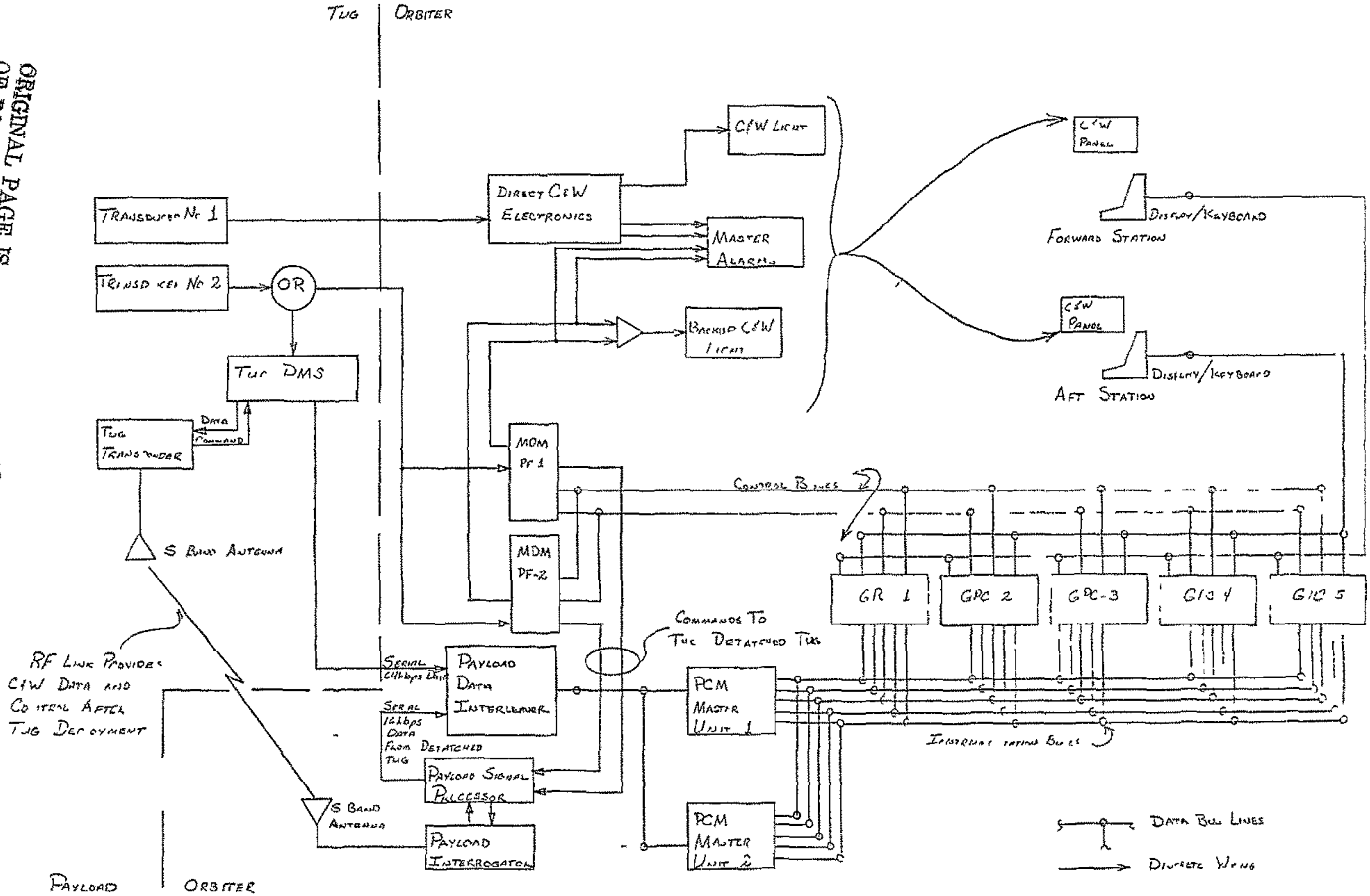

Figure 4 CAUTION AND WARNING IMPLEMENTATION FOR TUG PAYLOAD (TYPICAL)

6 3 1 TEST LIMIT CHANGING

The tolerance test limits for the primary C&W path (through C&W electronics) are inflight alterable by a series of switches at the C&W panels

The GPC test limits for the backup path are inflight alterable through the display/keyboards

6 3 2 OPERATION VIA RF LINK

Following the deployment of the Tug vehicle, the C&W function remains active until the Tug is a safe distance from the Orbiter During this period the data and command signals are transmitted between the Tug and Orbiter via an S-Band relay system The data from the Tug is acquired through the payload interrogator and payload signal processor components and is output to the interleaver in a 16 kbps serial data stream Commands from the Orbiter to the Tug are output from the GPC system payload MDM's to the payload signal processor The signal processor then outputs this data to the payload interrogator for transmission to the Tug This is illustrated in the lower portion of Figure 4

The hardwired redundant C&W system is no longer available once the Tug umbilicals are disconnected The C&W system then becomes simplex and relies on the RF relay link rather than hard wires

6 4 TUG SYSTEM C&W INPUTS & ANNUNCIATORS

TUG SYSTEM STATUS TO C&W	ANNUNCIATORS
LH_2 TANK PRESSURE	LH_2 TANK PRESSURE
LO_2 TANK PRESSURE	LO_2 TANK PRESSURE
N_2H_4 TANK TEMP 1	N_2H_4 TANK TEMP
N_2H_4 TANK TEMP 2	
N_2H_4 TANK TEMP 3	
FUEL CELL LO_2 PRESSURE	FUEL CELL LO_2 PRESSURE
FUEL CELL LH_2 PRESSURE	FUEL CELL LH_2 PRESSURE
DEPL ADAPT ARMED	DEPL ADAPT ARMED
APS ARMED	APS ARMED
TUG MAIN PROPL ARMED	TUG MAIN PROPL ARMED
AUX BATTERY TEMP	AUX BATTERY TEMP
SPACECRAFT DEPL ARM SAFE	SPACECRAFT DEPL ARM SAFE
H_E BOTTLE PRESS 1	H_E BOTTLE PRESSURE
H_E BOTTLE PRESS 2	
H_E BOTTLE PRESS 3	
UMB PANEL DISENGAGED	UMB PANEL DISENGAGED

Four symbols are used to form the bars of the bar chart Symbol *O* is used to designate those functions which are in the critical path For example, the first critical path is derived for the IUS and consists of the following functions Contract Software Development, Plan Ground Software Development, EDD-Executive/Tracking/Planning, Program Ground Track/Plan/Executive Software, Verify Executive/Track/Planning Software, IUS Mission planning and Optimization, IUS Abort planning, IUS Mission Specific EDD, IUS Mission Specific Program, IUS Mission Program Verification, IUS Mission Simulation Training, Conduct IUS mission Operations, and IUS Post-mission Reports None of those events can exceed its allocated time without slipping the program launch date The symbol *E* is used to designate the span of time beginning at the earliest time all constraints are met for a particular activity to begin. The symbol *L* is utilized to indicate the span of time from the latest possible time an activity can begin through its completion. Each symbol designates one week of activity. If an activity is not in the most critical path it will contain the symbol *E* and the symbol *L* and either the symbol *O* or +. In that context, the symbol *O* indicates the overlap between bars representing an early start and a late start For example the task "Analyze Tug Component Characteristics" requires seven weeks to accomplish. The earliest it can begin is February 1983 There are six consecutive *E* symbols followed by a single *O* symbol followed by six consecutive *L* symbols The *O* symbol is to be interpreted as a week shared between the *E* and *L* activity periods

The + sign indicates program "slack", that is, the activity is not critical and may be accomplished at any time between the first *E* and the last *L*

Figure 10 5 0-2 is a planning tool The next step in overall planning is to select the optimal calendar time for the accomplishment of each task, where the time is at the option of the planner. This eliminates the critical path from consideration but does allow the planner to choose the calendar period of accomplishment of the non-critical activities

One tool which aids in the selection of the optimum time is the requirement for allocation of resources to accomplish the tasks which are illustrated in the PERT network and the bar chart This is an interactive and iterative process and, therefore, only the first modification is illustrated. The PERT chart as it was initially formulated requires that a duration, or time of accomplishment be estimated The durations entered in the initial factors, one of which is the level and skill of manpower to be applied to the accomplishment of the task Table 10 5 0-1 presents the input information required to estimate the kind, type, and schedule of manpower requirements against the PERT network The ninety-six activities of the program are listed vertically, the horizontal axis defines the type of manpower to be applied to the activity and the matrix cell defined by the intersection of the horizontal and the vertical is the point at which the number of manhours estimated for the particular skill against the specific job is entered

JAN FEB MAR 1Q80 | APR MAY JUN 2Q80 | JUL AUG SEP 3Q80 | OCT NOV DEC 4Q80 | JAN FEB MAR 1Q81 | APR MAY JUN 2Q81 | JUL AUG SEP 3Q81 | OCT NOV DEC 4Q81 | JAN FEB MAR 1Q82 | APR MAY JUN 2Q82 | JUL AUG SEP 3Q82 | OCT NOV DEC 4Q82 | JAN FEB MAR 1Q83 | APR MAY JUN 2Q83 | JUL AUG SEP 3Q83 | OCT NOV DEC 4Q83

DESCRIPTION
CONTRACT SOFTWARE DEVELOPMENT
PLAN GROUND SOFTWARE DEVELOPMENT
EDD-EXECUTIVE/TRACKING/PLANNING
PROGRAM GROUND TK/PLAN/EX SOFTWARE
VERIFY EXECUTIVE/TK/PLAN SOFTWARE
IUS MISSION PLANNING AND OPTIMIZAT
IUS ABORT PLANNING
IUS MISSION SPEC EDD
IUS MISSION SPEC PROGRAM
IUS MISSION PROGRAM VERIFICATION
IUS MISSION SIMULATION TRAINING
CONDUCT IUS MISSION OPERATIONS
IUS POST MISSION REPORTS
EDD-TUG DOWNDATA/UPDATA/DOCKING/SI
ESTIMATE GROUND SOFTWARE SIZE
SELECT OPERATIONAL DATA SYSTEM
SIZE FACILITY/DESIGN PHYSICAL PLAN
CONSTRUCT PHYSICAL PLANT
INSTALL OPERATIONAL DATA SYSTEM
DEVELOP IUS PROCEDURES AND RULES
PROGRAM IUS MISSION SIMULATION
VERIFY TUG DNDATA/UPDATA/DOCKING/S
DEVELOP TUG PROCEDURES AND RULES
DESIGN TUG MISSION SIMULATION
TUG MISSION SPEC EDD
TUG MISSION SPECIFIC PROGRAM
TUG MISSION PROGRAM VERIFICATION
TUG MISSION SIMULATION TRAINING
CONDUCT TUG MISSION OPERATIONS
TUG POST MISSION REPORTS
ANALYZE TUG COMPONENT CHARACTERIST
PREPARE TUG SYSTEMS HANDBOOK
PUBLISH/UPDATE TUG SYSTEMS HANDBOO
PROGRAM TUG MISSION SIMULATION
TUG MISSION PLANNING AND OPTIMIZAT
TUG ABORT PLANNING
PREPARE TUG INTERAGENCY DOCUMENTS
TUG INTERAGENCY COORDINATION
PREPARE IUS INTERAGENCY DOCUMENTS
IUS INTERAGENCY COORDINATION
TUG NETWORK DATA HANDLING REQUIREM
TUG NETWORK DATA VALID PROCEDURES
TUG NETWORK VALID TESTS
TUG TRAINING REQ/CRIT/SIMSKED
DEVELOP TUG TRAINING MATERIAL
TUG CLASSROOM TRAINING
INSTALL OPERATIONAL CONSOLES/HARDW
EDD-IUS DOWNDATA/UPDATA/SIMULATION
PROGRAM IUS DNDATA/UPDATA/SIMULATI
VERIFY IUS DNDATA/UPDATA/SIM PROGR
MASTER LAUNCH SCHEDULE ANALYSIS
TUG MISSION CHARACTERIZATION
MISSION PHASE MANNING REQUIREMENTS
HIRE CONTROL ANS SUPPORT STAFF
OBTAIN SPACE TUG SYSTEM CHARACTERI
DESIGN NETWORK INTERFACE SYSTEM
DEFINE NETWORK TRACKING REQUIREMEN
NETWORK TRACKING VALID PROCEDURES
NETWORK TRACKING VALID TESTS
IUS MISSION CHARACTERIZATION
COMPUTER UTILIZATION PLAN
OBTAIN IUS SYSTEM CHARACTERISTICS
TUG DISPLAY FORMAT DESIGN
IUS NETWORK DATA HANDLING REQUIREM
IUS NETWORK DATA VALID PROCEDURES
IUS NETWORK DATA VALID TESTS
IUS DISPLAY FORMAT DESIGN
PLAN FLIGHT SOFTWARE DEVELOPMENT
EDD-IUS FLIGHT PROGRAM
PROGRAM IUS FLIGHT SOFTWARE
IUS FLT PROGRAM VERIFICATION
CONSOLE ORGANIZATION
PROGRAM TUG DNDATA/UPDATA/DOCKING/
PLAN FACILITY UTILIZATION
EDD-TUG FLIGHT PROGRAM
PROGRAM TUG FLIGHT SOFTWARE
TUG FLT PROGRAM VERIFICATION
MAINTENANCE SCHEDULE
DETERMINE IUS FAILURE MODES
IUS MISSION FAILURE EFFECTS
DESIGN IUS MISSION SIMULATION
ANALYZE IUS COMPONENT CHARACTERIST
PREPARE IUS SYSTEMS HANDBOOK
PUBLISH/UPDATE IUS HANDBOOK
IUS TRAINING REQ/CRIT/SIMSKED
DEVELOP IUS TRAINING MATERIAL
IUS CLASSROOM TRAINING
COMMON GND SW VALID TEST REQUIREME
CONSOLE POSITION GUIDELINES
IUS GND SW VALID TEST REQUIREMENTS
DEFINE IUS OPERATOR CERT/CRITERIA
DETERMINE TUG FAILURE MODES
TUG MISSION FAILURE EFFECTS
TUG GND SW VALID TEST REQUIREMENTS
TUG CONSOLE POSITION GUIDELINES
DEFINE TUG OPERATOR CERT/CRITERIA

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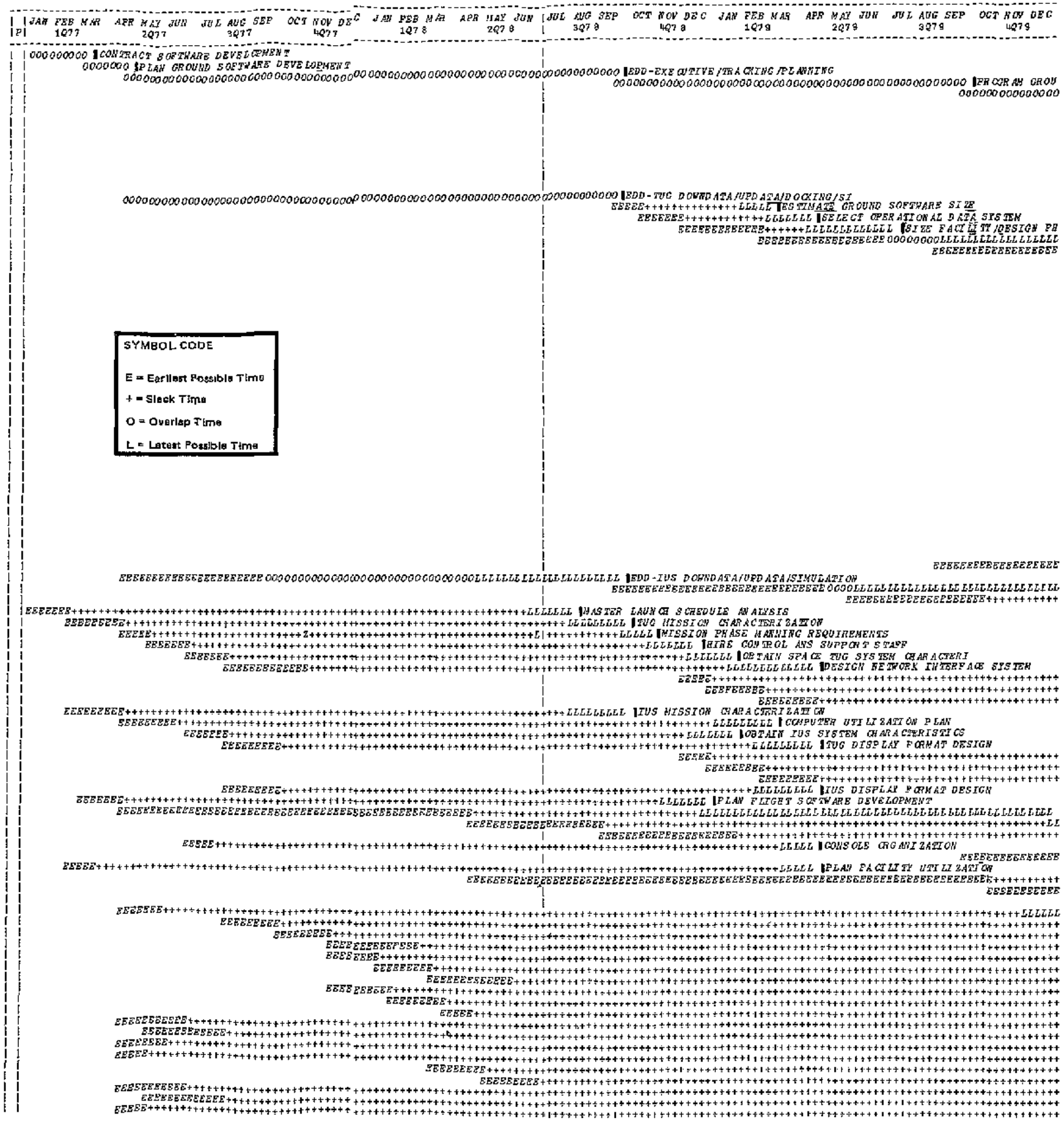

Figure 10 5 0-2 IUS/Tug Systems Development Schedule

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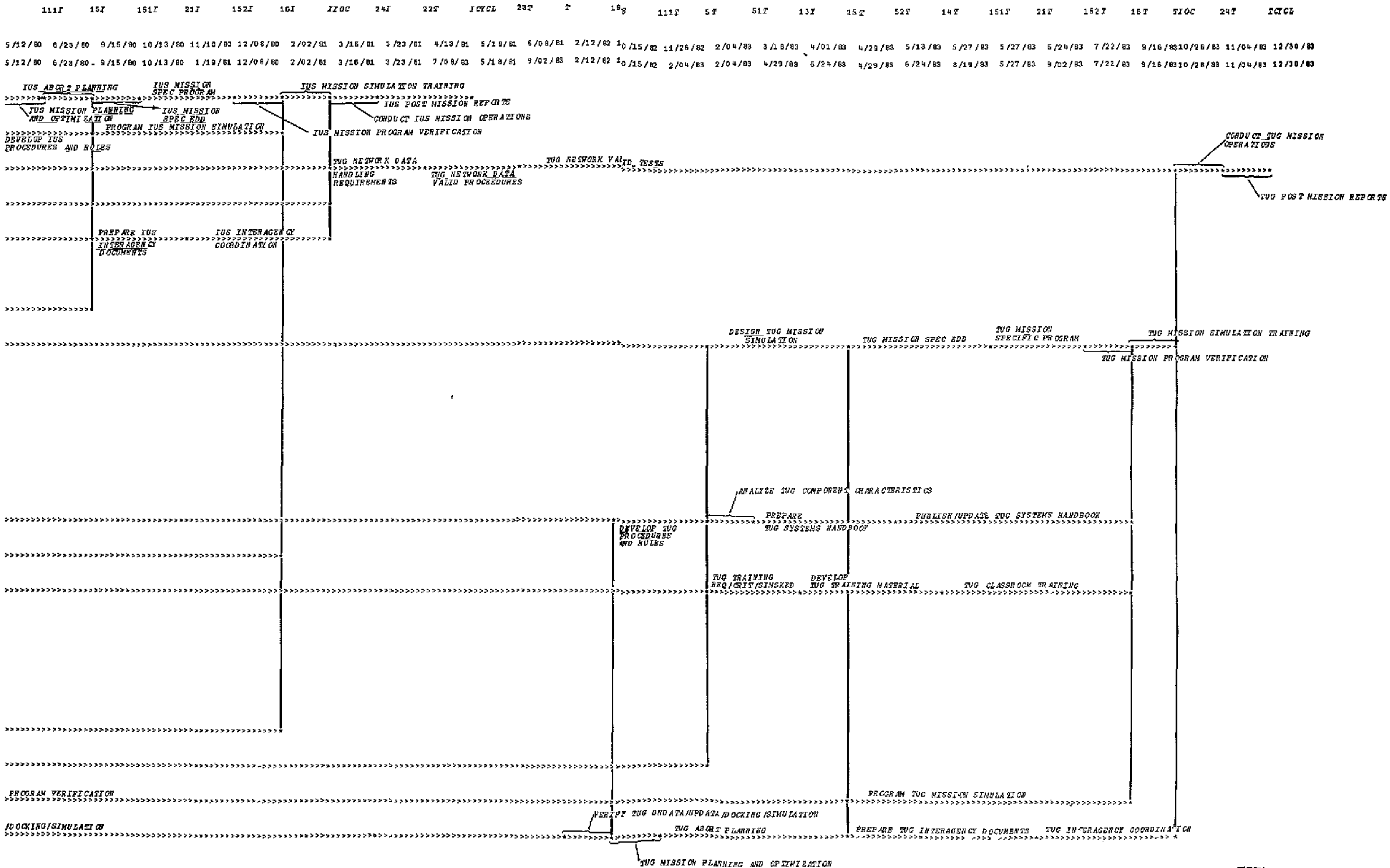

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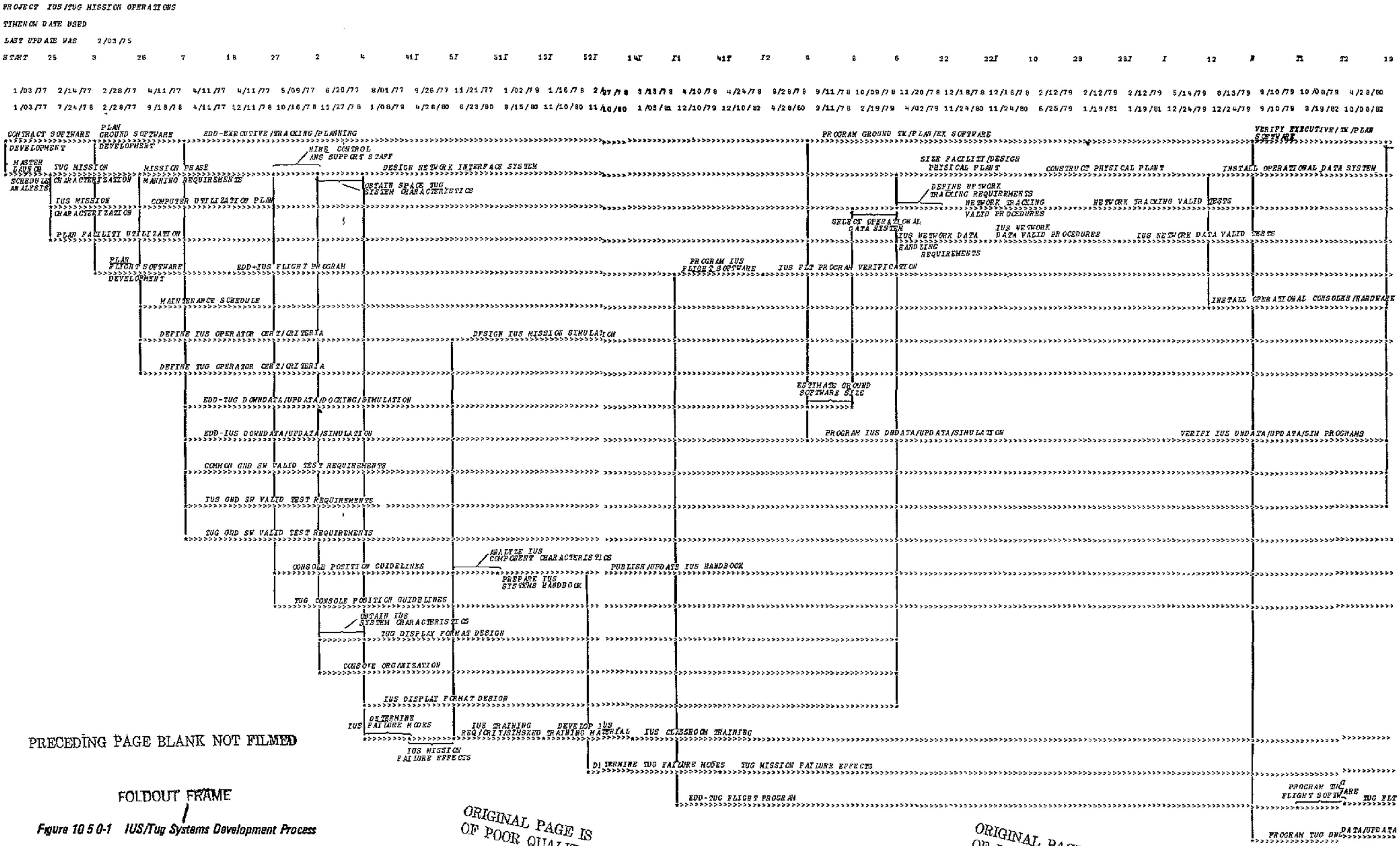

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Figure 10 5 0-1 IUS/Tug Systems Development Process

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